WHAT HAPPENED BEFORE THE BIG BANG?

ALL ABOUT SPACE™

ISSUE 137
DECEMBER 2022

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ISSUE 137

SCAN HERE TO GET OUR DAILY NEWSLETTER

What happened before the Big Bang? This month, we're taken back to a time before the universe began – or at least that's what we believe, that the cosmos as we know it simply didn't exist. Throw in a cyclic model or the idea that it's always been there – some cosmologists think that the Big Bang didn't really happen – and think how the galaxies, planets and stars you can see in the night sky even came to exist. It's an event that has the greatest minds questioning if there really was anything before the universe.

If you can't get enough of cosmology, then you're in luck this issue – our cover feature details the glitch in our universe: could what we believe to be the laws of physics actually break down the further into the cosmos we go?

Of course, with Christmas soon upon us, many will be getting gifts for our loved ones. If you're looking for some inspiration, turn to our gift guide for the very best ideas from HarperCollins, Sega Toys and more. Have a fantastic Christmas and see you in the New Year!

GEMMA LAVENDER
Content Director

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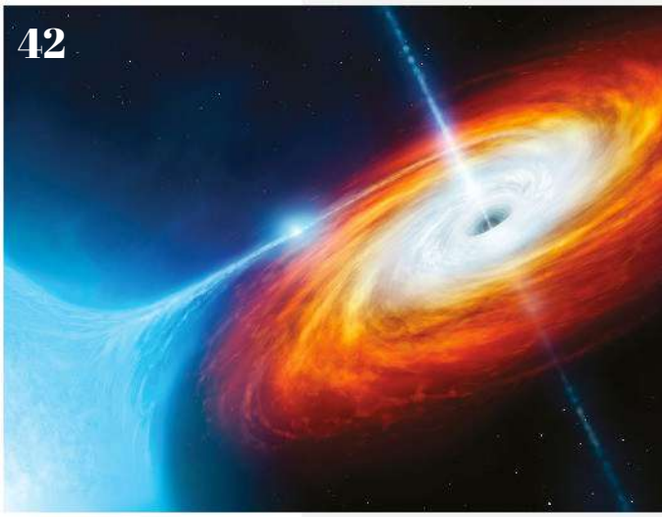

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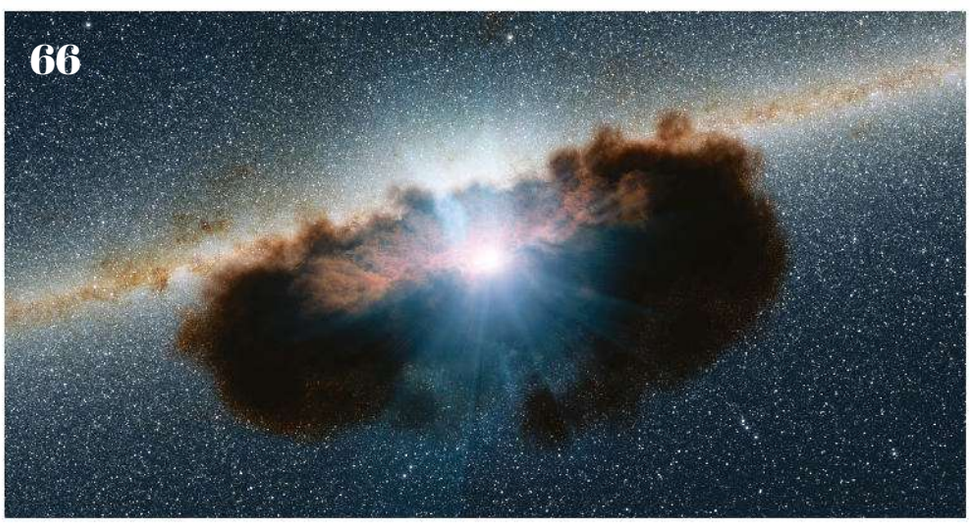

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28 October 2022

Webb's Pillars of Creation

James Webb Space Telescope scientists have released a second view of the iconic Pillars of Creation, this one peering deep into the mid-infrared (inset). The dust clouds appear to glow in blue tinges, looming in front of a red-hued background. "Thousands of stars that exist in this region disappear from view, and seemingly endless layers of gas and dust become the centrepiece," European Space Agency officials said.

Dust is an essential ingredient for star formation and helps scientists in figuring out the formation and evolution of the structure, which is located in the constellation of Serpens, some 7,000 light years away from Earth. Many stars are actively forming in these dense blue-grey pillars. When knots of gas and dust with sufficient mass form in these regions, they begin to collapse under their own gravitational attraction, slowly heat up and eventually form new stars.

© NASA, ESA

3 October 2022

Dancing to a galactic death

These galaxies may look like they're performing a cosmic waltz, but the spirals are actually trapped in a dance of death that will someday end in a violent crash. The Hubble Space Telescope recently captured an image of two galaxies, dubbed ESO 364-65 and ESO 364-66, collectively known as Arp-Madore 608-333, gradually warping each other with their gravitational forces.

The telescope, managed by NASA and the European Space Agency (ESA), took the image while it was turning around. The photo comes from a 'snapshot' program designed to make use of tiny slivers of time between other observations, since Hubble needs to use every second of its observing time to the best of its ability.

The warping galaxy observations are part of an effort to identify targets that will possibly be of interest for further study. For Hubble, the initiative means snapping photos of targets carefully selected because they're visible from whatever direction the telescope may be pointing.

So what will happen when these interacting galaxies inevitably collide? They might form an elliptical galaxy, and such a merger could also switch on star formation that happens so fast it could drain the combined galaxy of material for future stars.

© ESA/Hubble & NASA

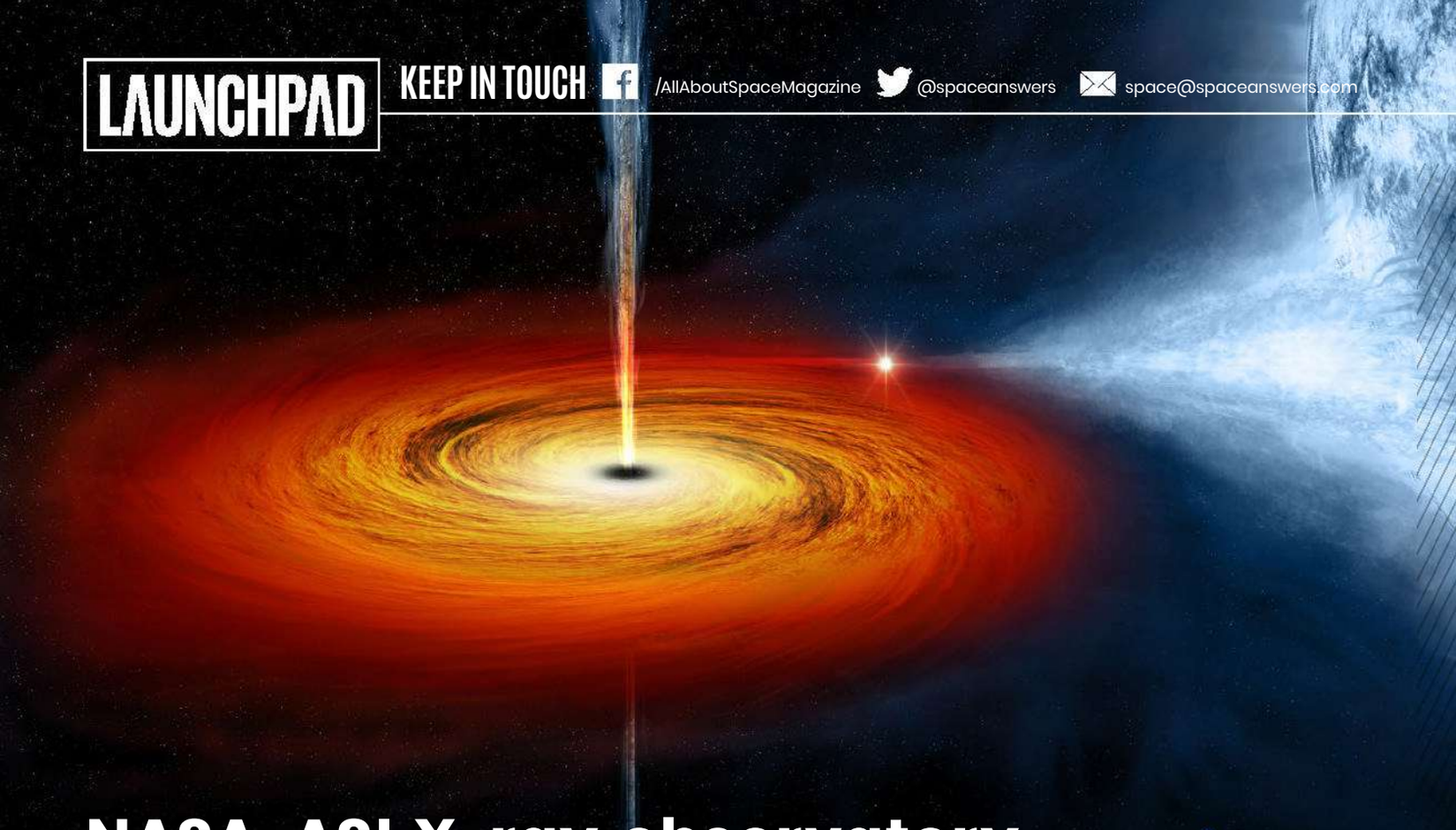
24 October 2022

A cosmic keyhole

It's not every day that you can peek through a keyhole in the cosmos, but Hubble did just that. A new photo of the reflection nebula NGC 1999 taken by the Hubble Space Telescope and released by NASA and the ESA on 24 October shows a peculiar portrait of the swirling cloud of gas and dust. The nebula is a relic of a star's formation – V380 Orionis, which can be seen in the centre of the image. The most distinctive feature of the photo, however, is the dark void in the heart of the nebula shaped like a keyhole.

When the nebula was first imaged by Hubble in 1999, it was believed that the dark central region was something known as a Bok globule. These globules are cold clouds of gas, dust and other molecules that are so dense that they block any light from passing through. It was only after subsequent observations of the nebula that astronomers learned that the dark region was actually empty space. At the moment the origin of this keyhole feature isn't known. The nebula is illuminated from the inside by the newborn star V380 Orionis, and the nebula itself is actually the leftover material from the star's formation. The star is white in colour owing to the intense heat of its surface – roughly 10,000 degrees Celsius (18,000 degrees Fahrenheit), or twice the temperature of the Sun – and it's estimated to be 3.5 stellar masses.

© ESA/Hubble & NASA, ESO



NASA-ASI X-ray observatory reveals how black holes swallow and spit out stars

The Cygnus X-1 binary features a black hole stripping material from a companion star, with material forming a hot accretion disc

Reported by Keith Cooper

The NASA–Italian Space Agency (ASI) Imaging X-ray Polarimetry Explorer (IXPE) has peered deep into the hot gas surrounding a black hole, teaching us how black holes swallow and spit out matter. IXPE launched in December 2021 to study some of the most highly energetic objects in the universe, including accreting black holes, neutron stars and pulsars. It does this by observing the polarisation of the X-rays emitted by these extreme objects. Polarisation is the principle by which sunglasses work – they block all light except that which oscillates in a specific direction. Similarly, the polarised X-rays that IPXE detects are electromagnetic waves vibrating mostly in a particular direction. The polarisation "carries information about how the X-rays were emitted," said lead researcher Henric Krawczynski of Washington University in St Louis. In regards to black holes, the polarisation also tells us "if, and where, [the X-rays] scatter off material close to the black hole," Krawczynski added

IXPE observed Cygnus X-1, which is an X-ray binary system consisting of a 21-solar-mass black hole and a 41-solar-mass companion star 7,200 light years away in the constellation of Cygnus, the Swan. The black hole's gravity is tearing matter from its stellar companion, and this matter is forming a stream of gas that spirals around the black hole and forms an accretion disc. Friction within the gas raises the temperature to millions of degrees, hot enough to emit X-rays. However, with frictional, magnetic and gravitational forces all in play within the disc, it has never been entirely clear to astronomers how some of that matter then falls across the event horizon and into the black hole's maw and how some of the matter is funnelled into bipolar outflows that escape the black hole.

IXPE's observations, combined with secondary X-ray observations by NASA's Nuclear Spectroscopic Telescope Array (NuSTAR) and the Neutron star Interior Composition Explorer (NICER) on board the International Space Station, shed light on the shape and location of the material emitting the X-rays around the black hole. They found the X-rays are being scattered off material in a coronal region around the black hole. A black hole's corona is formed of ultrahot plasma and is suspected to be involved in the production of jets of charged particles that are seen by radio telescopes racing away from black holes. The polarisation of the X-rays measured by IPXE suggests that Cygnus X-1's corona extends away from the black hole parallel to the plane of the accretion disc and perpendicular to the jets. Hence the corona is either sandwiching the in-spiralling matter, or actually forms the inner part of the accretion disc.

Furthermore, the corona and inner accretion disc seem to be misaligned relative to the orbital plane of the companion star around the black hole and the orientation of the outer accretion disc. This misalignment could have been caused as a result of the supernova that produced the black hole causing the black hole to spin at an angle to the system. This acute spin, and the gravity the black hole wields, could then have introduced torques in the inner disc, twisting and warping it. "These new insights will enable improved X-ray studies of how gravity curves space and time close to black holes," said Krawczynski.

A 2014 meteor is Earth's first known interstellar visitor

Reported by Tereza Pultarova

Astronomers have confirmed that a suspicious space rock that hit Earth in 2014 came from another star system, predating the famous 'Oumuamua by three years. Researchers found the meteor in the catalogue of NASA's Center for Near Earth Object Studies (CNEOS) in 2019. At that time, some of the data about the rock's trajectory was kept secret by the US Department of Defence (DoD), whose sensors collected them. But in March this year, the DoD released a statement confirming the measurements, allowing scientists to complete their calculation of the mysterious rock's origin. The 0.9-metre (2.9-foot) wide mini-asteroid, which entered Earth's atmosphere on 8 January 2014, arrived at a very fast speed of 215,974 kilometres (134,200 miles) per hour. It also followed an odd trajectory that suggested it may have come from outside the Solar System. By modelling the rock's path into the past, the authors of a new paper confirmed the tiny asteroid was indeed a newcomer into the Sun's corner of the Milky Way.

The confirmation makes the rock, named CNEOS 2014-01-08, the first known visitor from interstellar space, predating the asteroid 'Oumuamua that zipped past Earth in 2017. Only one year later, astronomers discovered the second interstellar object, the 0.5-kilometre (0.3-mile) wide comet Borisov. The short interval between those discoveries led astronomers to believe that smaller interstellar rocks, only a few metres wide, must be much more common in the Solar System and even regularly cross paths with our planet.

The researchers believe that interstellar space rocks might hit Earth's atmosphere about once per decade. Analysing those meteors could provide new insights into the chemistry of distant star systems. "By extrapolating the trajectory of each meteor backwards in time and analysing the relative abundances of each meteor's chemical isotopes, you can match meteors to their parent stars and reveal insights into planetary system formation," the authors said in the paper. "[Some chemical] elements can be detected in the atmospheres of stars, so their abundances in meteor spectra can serve as important links to parent stars."

Because most meteoroids burn up in the atmosphere before making it to Earth's surface, and because retrieving those that do is extremely time-consuming and challenging on a technical level, the researchers propose creating a worldwide camera network capable of making spectroscopic measurements, analyses of the light-absorption fingerprints of arriving space rocks that could reveal their chemical compositions. CNEOS 2014-01-08 exploded above the ocean near Papua New Guinea, and scientists believe that some pieces of the rock may have survived the journey through Earth's atmosphere and fallen into the sea. An expedition to attempt to retrieve some of the fragments is planned for 2023.

A Space rocks from other solar systems may be crossing Earth's path every ten years or so

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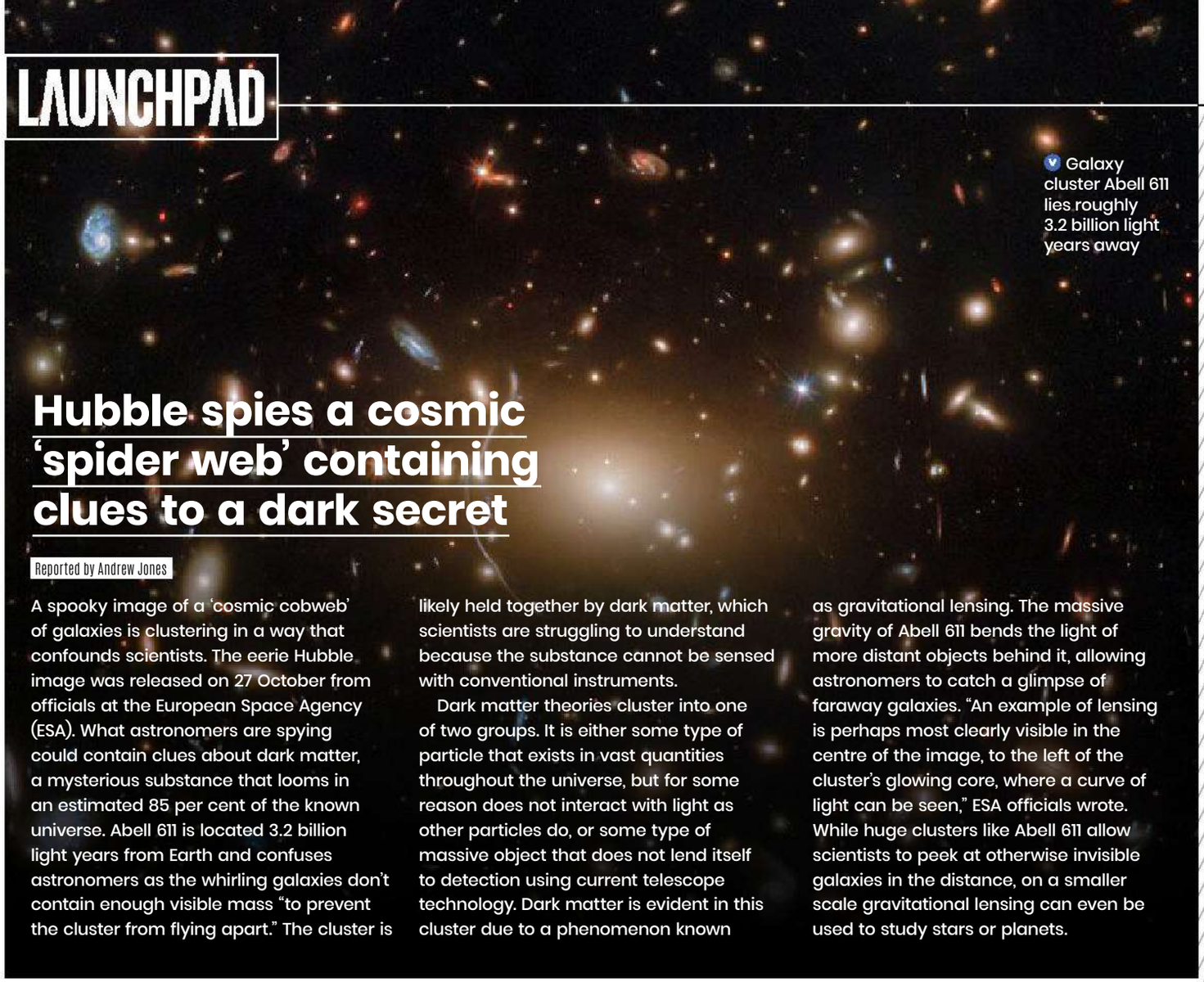


Galaxy cluster Abell 611 lies roughly 3.2 billion light years away

Hubble spies a cosmic 'spider web' containing clues to a dark secret

Reported by Andrew Jones

A spooky image of a 'cosmic cobweb' of galaxies is clustering in a way that confounds scientists. The eerie Hubble image was released on 27 October from officials at the European Space Agency (ESA). What astronomers are spying could contain clues about dark matter, a mysterious substance that looms in an estimated 85 per cent of the known universe. Abell 611 is located 3.2 billion light years from Earth and confuses astronomers as the whirling galaxies don't contain enough visible mass "to prevent the cluster from flying apart." The cluster is likely held together by dark matter, which scientists are struggling to understand because the substance cannot be sensed with conventional instruments.

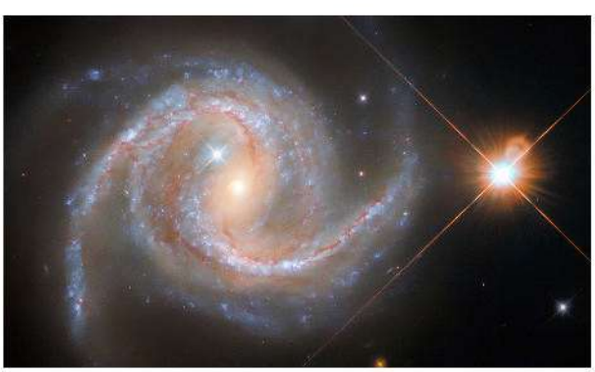
Dark matter theories cluster into one of two groups. It is either some type of particle that exists in vast quantities throughout the universe, but for some reason does not interact with light as other particles do, or some type of massive object that does not lend itself to detection using current telescope technology. Dark matter is evident in this cluster due to a phenomenon known as gravitational lensing. The massive gravity of Abell 611 bends the light of more distant objects behind it, allowing astronomers to catch a glimpse of faraway galaxies. "An example of lensing is perhaps most clearly visible in the centre of the image, to the left of the cluster's glowing core, where a curve of light can be seen," ESA officials wrote. While huge clusters like Abell 611 allow scientists to peek at otherwise invisible galaxies in the distance, on a smaller scale gravitational lensing can even be used to study stars or planets.

Milky Way stars photobomb a spiral galaxy in a stunning Hubble photo

Reported by Doris Elin Urrutia

Hubble captured the sight of a beautiful spiral galaxy adorned with the sparkle of two nearby stars. NGC 5495 lies 300 million light years from Earth, far behind the jewel-like celestial bodies to the top-left of the galaxy's centre, and another to the right. These are stars within the Milky Way, Earth's home galaxy, which like NGC 5495 is a spiral galaxy. According to the ESA, which wrote a description of the "stately sweeping spiral arms" of the galaxy in a new NGC 5495 image, 60 per cent of galaxies are spiral galaxies. This means that most of the stars in the universe are contained within a galaxy like our own, or like the one seen in the new Hubble image. NGC 5495 is a Seyfert galaxy. These are galaxies with activity at their cores. The most extreme version of active galactic nuclei (AGN), called quasars, are the brightest objects in the known universe. This sort of glowing galactic heart is powered by the might of a supermassive black hole, which astronomers believe lie at the centres of most, if not all, galaxies in the cosmos.

When these gravity pits accrete a lot of material around the outside, the material heats up and begins to glow. NGC 5495 isn't in the quasar category, but it's still considered a churning AGN. NGC 5495 is also lovely to behold because it's conveniently oriented face-on to observers on Earth, allowing its core and spiral arms to be clearly visible. Although it's not too visible from this perspective, spiral galaxy NGC 5495 is probably enveloped in a halo that lies just above and below the galactic disc.



Spiral galaxy NGC 5495 in the constellation Hydra

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The award-winning Sky-Watcher Explorer 130 is a fantastic choice for the serious beginner and also receives high marks from more seasoned astronomers. With an extremely useful 130mm of light-gathering aperture, this telescope is a highly capable all-rounder for the observation of the Moon, bright planets, nebulae, galaxies and star clusters. It's supplied with an EQ2 equatorial mount, which when polar aligned will allow you to easily track objects as they move across the night sky via its slow-motion control cables.

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A: Green

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C: Blue

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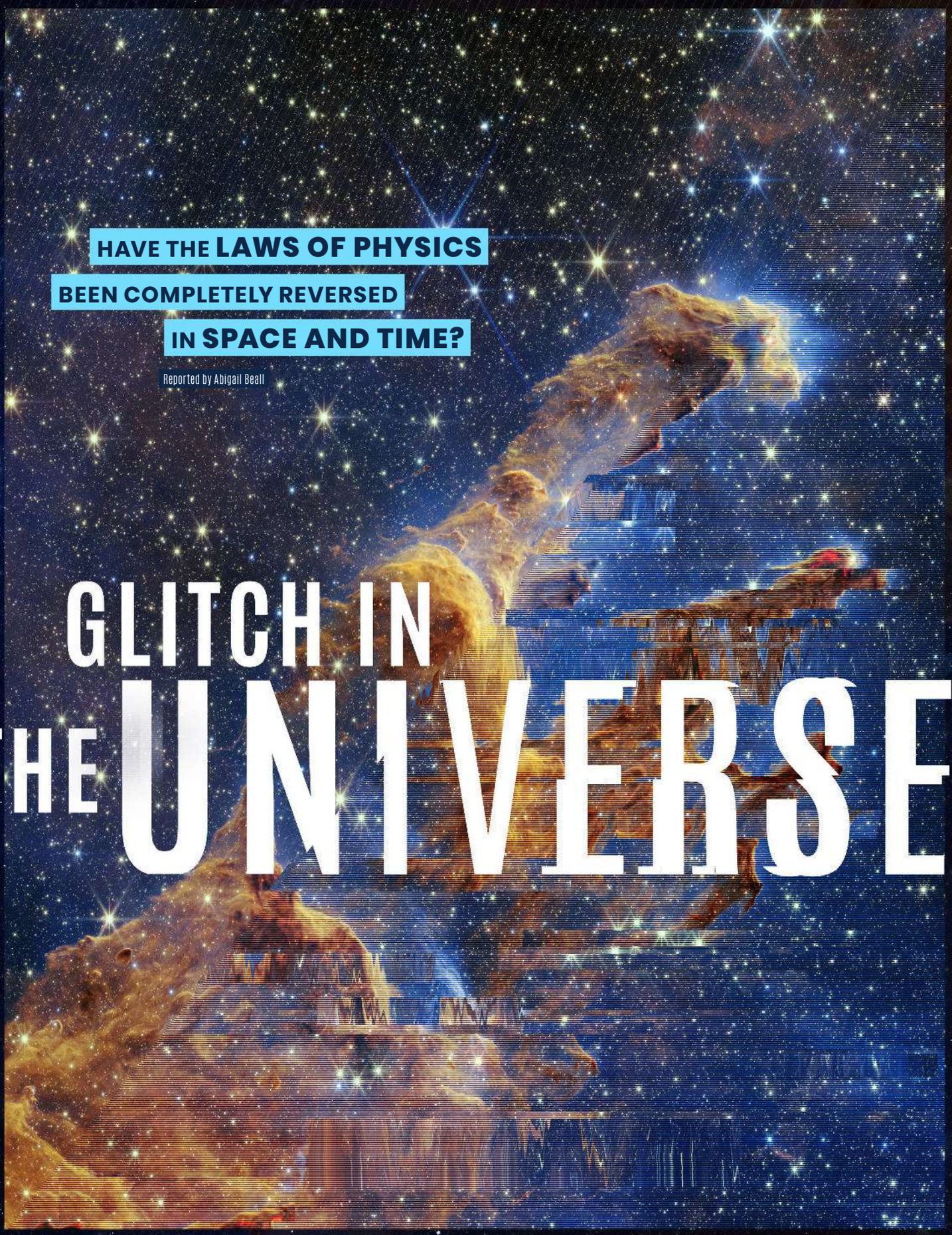


HAVE THE LAWS OF PHYSICS BEEN COMPLETELY REVERSED IN SPACE AND TIME?

Reported by Abigail Beall

GLITCH IN THE UNIVERSE

When it comes to the laws of physics, you could be forgiven for thinking there are rules which apply no matter where you are in time or space. After all, this is what we are taught. But everything you think you know about the universe could be wrong, thanks to a glitch. The laws of physics may be different across the universe, in both space and time. This is according to a theory that has been in testing for over two decades that, if proven correct, could rewrite the laws of physics altogether. There's a set of numbers known as fundamental constants which play a vital role in physics in determining how particles interact with each other.

Quantum electrodynamics, or QED, describes how the electromagnetic force works on the quantum level. In QED there's an important number called alpha. It governs how light particles interact with electrically charged particles like electrons, muons and tau. Alpha, which is also called the fine-structure constant, is calculated using the speed of light, Planck's constant and the charge of an electron. It can be measured experimentally and has been measured to a strong degree of precision on Earth. One divided by alpha has been measured to be 137.035999074, with an experimental uncertainty of just 0.000000044. However, nobody knows exactly why alpha is the number it is, and there are increasing hints the constant might not be so constant throughout the universe.

Alpha can be measured by studying light coming from distant galaxies. When light hits an atom, it's only absorbed if the energy is equivalent to the energy needed to shift the electrons up an energy level. These electrons will be unstable at this new energy level, so will fall down again and release a photon with a wavelength equivalent to the light that was absorbed. Alpha determines how electrons interact with the nucleus of an atom because it changes how strong the attraction is. If alpha changed, the wavelength of light absorbed by atoms would also change. By studying light emitted from the gas near distant objects, like quasars, scientists can study alpha.

In 1998 a team led by Professor John Webb at the University of New South Wales (UNSW) in Sydney, Australia, became interested in studying alpha in different galaxies. "In 1998 I started working with Webb at UNSW as an honours student, finishing up my undergraduate degree in physics," says Michael Murphy, who is now a professor of astronomy at Swinburne University of Technology in Melbourne. "John had just started a collaboration with Victor Flambaum and Vladimir Dzuba in the physics department there to try to measure possible variations in alpha using quasar spectra."

Flambaum and Dzuba were atomic physics experts, while Webb was an expert in studying quasar absorption lines. "It was a great match of expertise, and soon they had their first results," says Murphy. The results were interesting. They showed that between 12 and 6 billion years ago, alpha had increased by an average of six parts in a million. This was not enough to significantly affect physics at that time, but it was enough to keep the researchers interested. "It was my job to start trying to understand what might be wrong with these results – the less-than-glamorous but hugely important hunt for systematic errors," says Murphy.

After finishing his honours, Murphy embarked on a PhD on the same topic, again working under Webb. This time he focused on trying to do the measurements as well as trying to understand how they might be affected by systematics. Years later, Murphy published a study in 2010 working alongside Webb, Flambaum and Professor Bob Carswell at the University of Cambridge. The study looked at absorption spectra from quasars in around 300 different

"There are hints the constant might not be so constant throughout the universe"

© NASA, ESA

galaxies. This time, the results were more convincing. They suggested that alpha varies by about one part in 100,000. On top of this, it seemed the number varied from one side of the universe to the other as we look at it.

If alpha were to be different across the universe, it would have huge implications for the laws of physics. "It would be akin to observing that the advance in Mercury's perihelion didn't quite match Newton's theory of gravity," says Murphy. "In that case, a completely new theory with a completely different concept of how gravity worked was required to explain it."

Observing a variation in alpha, or another fundamental constant, would be a sign that the Standard Model of particle physics, our theory of everything except gravity, is fundamentally incorrect. "It would mean we'd have to come up with a new theory altogether, possibly one with completely different concepts of how our universe works at a fundamental level," says Murphy.

Much theoretical physics research today focuses on trying to understand what the next most fundamental theory of the universe is, with many physicists certain that the Standard Model is not complete. For example, the Standard Model does not explain quantum gravity, and it's also incompatible with Einstein's theories of relativity. "Observing a variation in alpha would be a hugely important guide to what any new theory has to explain," says Murphy. "Just like Mercury's anomalous perihelion advance helped guide Einstein's general theory of relativity." If we discovered that the fine-structure constant varied throughout the universe, this would also help explain the mystery of why alpha is perfect for life.

The ESO commissioned an ultra-stable and precise spectrograph for its VLT

An artist's impression of one of the oldest quasars

Mysteriously, alpha is just right for life as we know it to exist. In other words, if alpha changed, the universe would look totally different. "If the fundamental constants were significantly different, any life as we know it could not appear," says Flambaum, who has worked on experiments to study alpha since Webb's experiments in 1998. If alpha were much smaller, the attraction between charged particles would be weaker, and molecular bonds – also known as covalent bonds – which rely on atoms sharing electrons, would fall apart at lower temperatures. This would have drastic effects on a huge number of processes necessary for life – molecular bonds are crucial for forming water, carbon dioxide and methane, for example.

On the other hand, if alpha were bigger protons would repel each other so strongly that the nuclei inside atoms couldn't stick together. If it were even larger than this, nuclear fusion within stars wouldn't be able to occur, meaning carbon, the element on which life is based, could not be produced. Luckily for us, alpha is just right. But nobody knows why. If alpha changes across the universe, however, then it makes sense that we appeared in the part where it is ideal for life to exist.

> **"It would mean we'd have to come up with a new theory altogether"**
> **Michael Murphy**

"Variation of the fundamental constants in space provides a natural explanation: we just appeared in the area of the universe where the fundamental constants are good for us," says Flambaum. "The universe is very large. Therefore the variation inside the visible universe may be small and hard to detect," he says.

In 2011 and 2012, results came out that suggested alpha could vary across the sky. Researchers used the Keck telescopes in Hawaii and the Very Large Telescope

SPACE-TIME'S NUMBERS

The six fundamental constants that shape the universe and allow life to exist on Earth

Alpha
The fine-structure constant, or alpha, determines the strength of electromagnetic interactions, like the bonds between electrons and other particles.

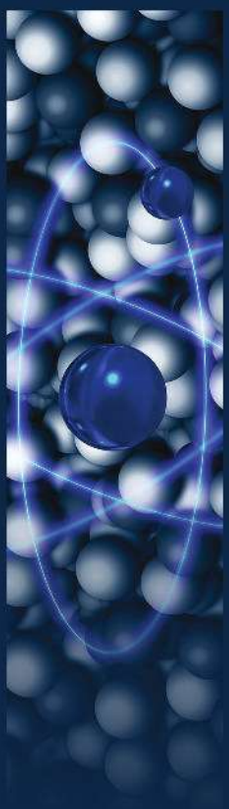
Gravitational constant
This constant, or G, defines the level of attraction between two objects. It determines why the Moon orbits Earth and why Earth orbits the Sun.

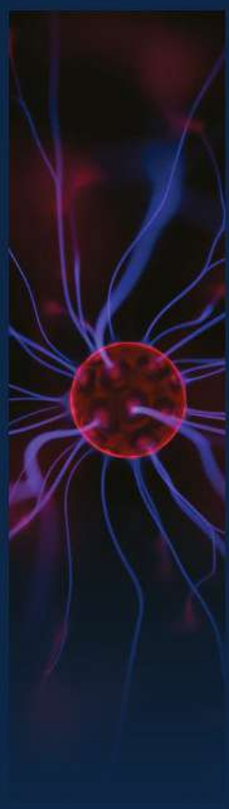
Elementary charge
The value of charge on an electron, or e, is called the elementary charge. It used to be called the electron until the particle was discovered.

Planck's constant
This relates the energy carried by a photon to its frequency. It forms the basis of how we have measured the kilogram.

Light speed
The speed of light in a vacuum, or c, is the maximum speed at which all conventional matter can travel.

Electric constant
Also referred to as vacuum permittivity, the electric constant relates the units for electric charge to mechanical quantities such as length and force.





WHAT IF THESE NUMBERS CHANGED?

Fine-structure constant
If alpha were larger, nuclear fusion within stars wouldn't be able to occur, meaning carbon, the element on which life is based, couldn't be produced.

Gravitational constant
If this were smaller, planets might not orbit around stars, and whole galaxies might fall apart. If G were larger we might not be able to survive on Earth.

Elementary charge
If the elementary charge of particles were to change, we'd see alterations on a more subatomic level, especially in the way charged particles interact with each other.

Planck's constant
If Planck's constant were to increase greatly, it could mean atoms cease to exist altogether, as electrons could be freed from their nuclei very readily.

Light speed
If the speed of light changes across the universe it might mean our estimates about the size and even the age of the universe could be wrong.

Electric constant
If this were greater the force between two separate electric charges would be weaker. This would have a huge impact on electromagnetism as we know it.

© NASA/ESA; ESO; Unmismoobjetivo

UNIVERSE'S GLITCH

The cosmos might look completely different the further you move from Earth

The fine-structure constant

On Earth, alpha is just right for life to exist. Any larger and atoms would fall apart; any smaller and molecular bonding could not happen.

Measuring alpha

We can study the value of alpha at different parts of the universe by measuring the wavelength of absorption from objects like distant quasars.

Almost 14 billion years ago

Looking back this far, we are studying the very first light in the universe. The further away we look, the more hints there are that alpha is different.

300 quasars

In 2010 a study looking at 300 distant quasars showed hints that alpha varies across the universe along a specific axis.

Alpha on Earth

On Earth we know alpha to a high degree of certainty; one divided by alpha is 137.035999074, with an uncertainty of just 0.000000044.

10 billion years ago

In 2011 and 2012, results came out that suggested alpha could vary by one part in 100,000 when looking 10 billion years ago.

6 billion years ago

The first results suggested that between 12 and 6 billion years ago alpha increased by an average of six parts in a million.

What does it mean?

If alpha varies across the universe, it could mean our theory of everything quantum, the Standard Model of particle physics, is wrong.

> **"If the constants were different, life as we know it could not appear"**
> **Victor Flambaum**

in Chile. They discovered that alpha could vary by one part in 100,000 when you look 10 billion years apart. Flambaum says that more recent measurements indicate a variation of alpha throughout space, but Murphy isn't so certain.

Between 2013 and 2015, Murphy and his colleagues in Europe and India identified some problems with the spectra recorded by the largest optical telescopes on Earth that had been used to study the quasars. "The spectrographs on those telescopes were slightly distorting the spectra in just such a way that could mimic the signal of a varying alpha," says Murphy. However, the team couldn't say for sure that this explained all of the previous results because to measure this effect they had to use historical observations of asteroids and stars like our Sun.

"There are not so many of these that are useful, so we're only able to sketch out a rough history of these distortions through the same decade or two when the quasar observations were being taken," says Murphy. "Still, to my mind this really undermines any confidence you could have in the early quasar results."

In 2017 Webb, along with Vincent Dumont, then of the University of California, Berkeley, refuted these results. They claimed the data analysis was flawed and applied only to a subset of the results derived from the Very Large Telescope, not the original results. More recent work completed by Murphy found no evidence for variations in alpha, down to just a few parts per million precision. However, again he says they cannot yet rule out the suggestion it changes across the sky.

The alpha debate may be answered once and for all by utilising the European Southern Observatory's ultra-stable and precise spectrograph on its Very Large Telescope, called ESPRESSO (Echelle SPectrograph for Rocky Exoplanets and

The Milky Way stretches above Paranal Observatory, home to the Very Large Telescope

© ESO

Stable Spectroscopic Observations). "This is the perfect machine for recording spectra of quasars to measure alpha," says Murphy, who is a member of the ESPRESSO science team. "It won't have any of the distortions that plagued the more 'general-purpose' spectrographs we'd used before."

ESPRESSO has already started gathering data, and results could be produced in the next few years. "We already have some data on quasars, and I must say, it's the best data I've seen by a long way," says Murphy. Yet the team will have to wait until they have analysed thousands of measurements before ruling anything out. Whatever the outcome, it's sure to improve our understanding of the cosmos.

Abigail Beall
Space science writer
Abigail is features editor for physics and technology at *New Scientist*. She has a master's degree in physics and is author of *The Art of Urban Astronomy: A Guide to Stargazing Wherever You Are*.

A very distant quasar powered by a black hole with a mass 2 billion times that of the Sun

WHY DOESN'T THE UNIVERSE MAKE SENSE?

Astrophysicists reveal what could be causing the glitch

If alpha weren't a constant, what would this mean for our understanding of the universe?
It would be akin to observing that the advance in Mercury's perihelion didn't quite match Newton's theory of gravity. In that case a completely new theory was required.

Professor Michael Murphy, Swinburne University

Where are we at now in terms of understanding if alpha is the same everywhere in the universe?
Astrophysical measurements by the John Webb group based on the quasar absorption spectra of ions indicate variation of alpha in space. This group made measurements based on over 300 absorption systems across the skies using original methods and made numerous tests of the results. Other groups used small samples of data and do not see the variation yet. All new data is based on the same Many-Multiplet method. There are no direct contradictions, but Webb group results are considered to be unconfirmed.

Professor Victor Flambaum, University of New South Wales

Why are the fundamental constants so important to physics?
A fundamental constant can be defined as being a parameter for which the value doesn't arise from the theory. They are quantities that can only be measured. Testing their constancy is in itself a test of the theories we use. They allow us to test the domain of their validity, and if their constancy doesn't hold true new physics should arise. If we detect a variation, either in time or by local environment conditions, then we would expect that they impact our current interpretation of the universe.

Ana Catarina Leite, PhD student at the Faculdade de Ciências da Universidade do Porto

Do you think that alpha varies across the universe?
No. In 1998 a group studying quasar absorption system spectra claimed a detection of a variation in alpha. However, more recently the same researchers performed a recalculation of systematic errors using new techniques and showed that there's no compelling evidence for any variation in alpha from quasar data. Furthermore, it follows from analyses with data from the cosmic microwave background and the abundances of light elements such as helium and deuterium that the value of alpha in the early universe is the same as its present value.

Susana Landau, Universidad de Buenos Aires

"The variation inside the visible universe may be small and hard to detect"
Victor Flambaum

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MICROBOT EXPLORERS

This new generation of all-access planetary probes will delve further than ever before

From the moment the Soviet Union landed Lunokhod 1 on the Moon in November 1970, scientists have been working tirelessly to create more efficient and effective methods for searching a planet's surface. We have seen rovers, landers and probes, but a team from the Department of Mechanical Engineering at the Massachusetts Institute of Technology (MIT) is working on microbots, the next generation of planetary investigators. These tiny spherical robots – often no larger than a baseball – are able to hop, bounce and roll around the surface of a planet, get into crevices and negotiate obstacles in ways that traditional rovers can't.

Engineers are hoping to reduce microbots to just ten centimetres (four inches) in diameter and have them weighing no more than 100 grams so they are able to get themselves into hard-to-reach places. They would be constructed of lightweight polymers and carry miniaturised scientific equipment for research. Many of the key components encased in the machines will be around the size of a coin, with the mass spectrometer measuring just 0.6 cubic centimetres (0.04 cubic inches).

The idea is to deploy hundreds of microbots on the surface of a planet, using an orbital craft to carry them there and an air bag system to ensure they're intact when they hit the planet's surface. From there, the microbots will spread out in teams, scouring the planet's surface and finding their way into cracks and caves. This will enable in-situ examination of the planet's composition, history and chemical structure. They will then send this information back to the surface, where it can be stored and communicated to teams back on Earth.

The microbots would have to work in a relay to get the information back to the surface, as electromagnetic waves struggle to get through rocky structures. This means that the information would be transmitted using high-frequency waves, jumping from

bot to bot until the signal is eventually able to be picked up on the surface.

A dielectric elastomer actuator – an elastic dielectric film placed between stretchy electrodes – creates the hopping movement of the microbots. When a current is passed through this, the electrodes are stimulated and laterally expand the film. This rapid expansion enables a microbot to hop on its bistable leg and travel across the planet's surface, easily traversing obstacles such as rocks. Each hop could take a microbot as far as a metre (3.3 feet), enabling it to travel dozens of metres every day, collecting important scientific information as it goes.

Mars would be one of the first obvious ports of call for this generation of planetary explorers. There has been an awful lot of analysis of the Red Planet recently, but the opportunity to go deeper than ever before is one the team at MIT will find hard to pass up. The Moon, with its pockmarked surface, will be another key area for the microbots to be deployed, but any planet or satellite with an inhospitable, rocky surface will be on the radar for these access-all-areas robots.

1 Size matters
The miniature robots will ideally only be around ten centimetres (four inches) in diameter, enabling them to reach and explore tiny gaps.

2 Equipment
They'll be fitted with a processing unit, camera, mass spectrometer, hard drive, sensors and other devices for recording and transmitting data.

3 Inside the planet
The microbots will enter crevices and caves in order to search for data hidden beneath the surface.

4 Team landing
Thousands of microbots will be deployed on the surface of the planet, enabling them to spread out and operate in teams.

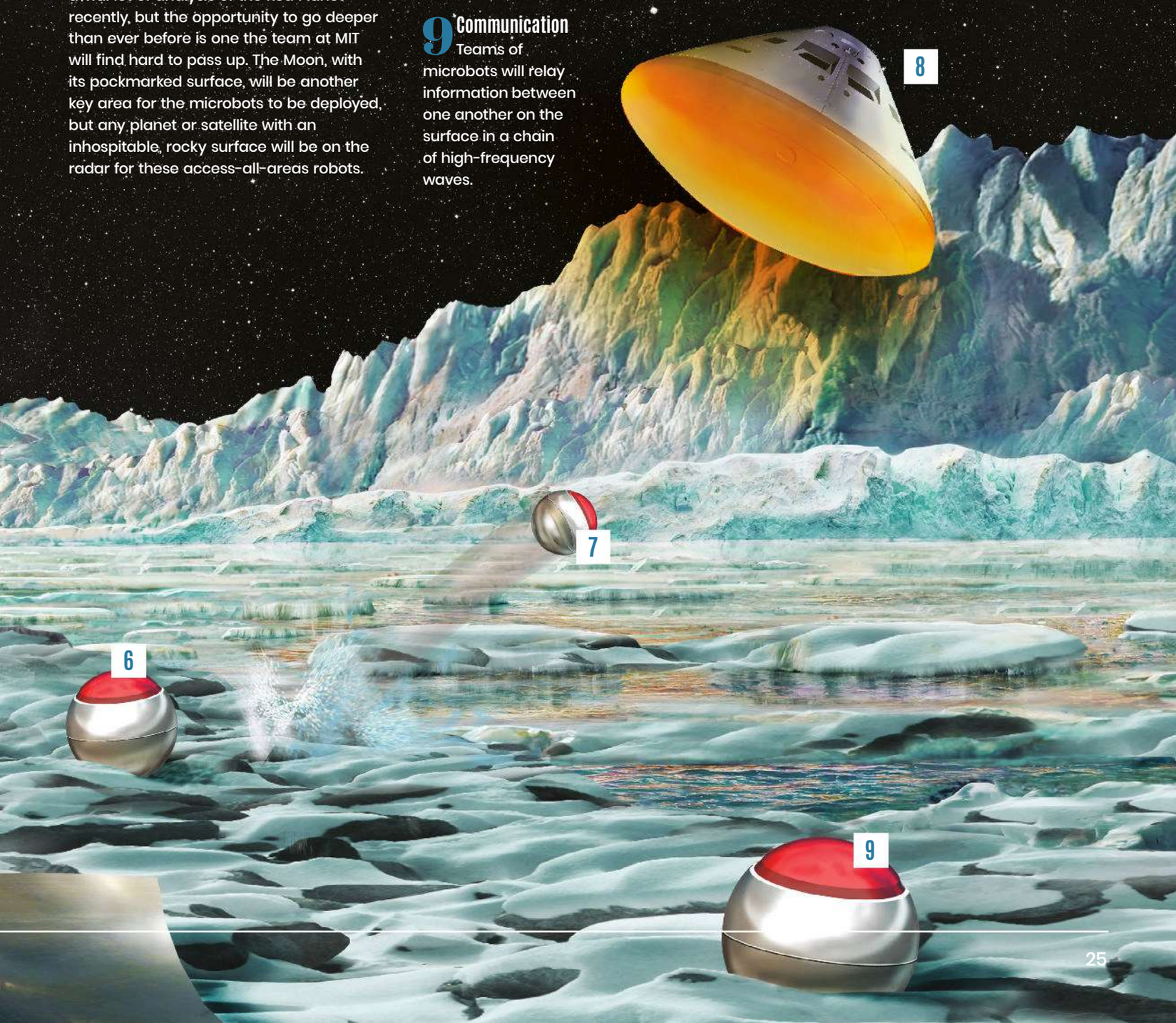
5 Low power
Due to the efficiency of the hopping mechanism, low-energy, low-weight fuel cells can be used for power over heavier batteries.

6 Materials
Each device will be constructed of a lightweight but durable polymer, which should reduce cost and weight.

7 Hopping
Using a rapidly expanding dielectric film, the robots will be able to hop up to a metre (3.3 feet) at a time in any direction.

8 Deployment
Microbots will be dropped by an orbital craft from above a planet's surface and will use air bags to cushion their landing.

9 Communication
Teams of microbots will relay information between one another on the surface in a chain of high-frequency waves.



BIO+

Dr Florence Raulin-Cerceau

Raulin-Cerceau is an associate professor at the National Museum of Natural History in Paris, France, and is also on the board of directors for METI International. This organisation takes a more active approach than the SETI Institute. Her research primarily consists of the history of SETI and astrobiology.

© Getty Images

Dr Florence Raulin-Cerceau

"We've probably been detected by extraterrestrials"

Messaging Extraterrestrial Intelligence's vice president Dr Florence Raulin-Cerceau reveals why if intelligent alien civilisations have located us, we should be talking back, and how we need to communicate

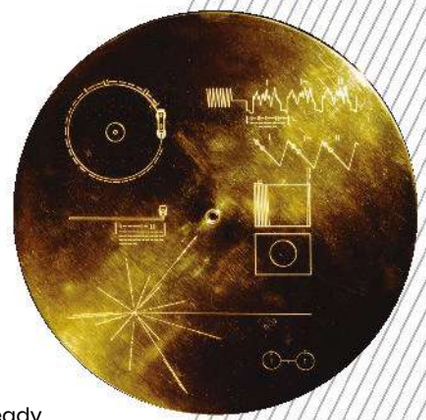
Interviewed by Lee Cavendish

What's your role at METI International?
My research is focused on astrobiology and the pioneers of SETI, because there were pioneers at the end of the 19th century who had projects to send messages to the Moon, Mars and Venus. These projects were not put into practice – they were just theoretical – but it was interesting to see that even at this time, more than a century ago, some people thought it was possible to send a message to other planets, even with it being the planets in our Solar System and not exoplanets.

But the scientific reflection was interesting because it's funny to see that a century later, with our own thoughts, we are thinking about using the same medium of communication in the message – for instance, using mathematics to somehow dialogue with aliens. Mathematics seems to be the easy way to begin a message; not the whole content, but to begin the message with mathematical concepts, and we are doing the same thing now. It's interesting to see the conversions between the first ideas at the end of the 19th century and now.

What benefits do you think actively messaging alien life has over passively watching for signals?
This is one of [METI president] Douglas Vakoch's aims at METI. He wants to send a message to other planets because he thinks that the inhabitation of Earth is already detectable. We already have radio signals, TV signals and many other signals that are spread out into outer space. He doesn't know exactly, but he suggests that it's already possible to be detected by aliens because a lot of our radio signals, and many other signals, can be picked up by alien civilisations elsewhere in the cosmos.

His opinion is that if we are detectable, it's not really dangerous to send messages, and perhaps we have to provide the first step in this organisation because it's important for future generations to know if we are alone or not in the universe. Our signals, whether artificial or natural, come from human activity, and for Vakoch it's important to try and have contact with what could turn out to be another civilisation in the galaxy, even if he doesn't know where the civilisation is.

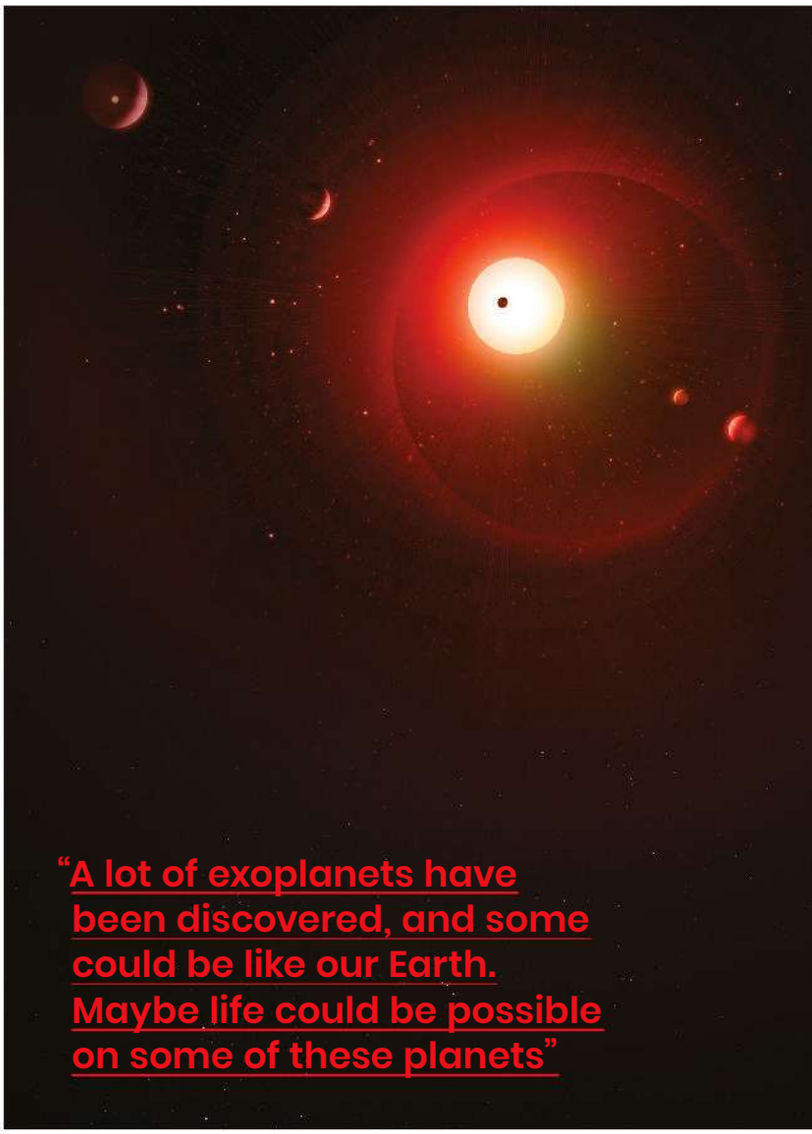


Voyager's Golden Record includes a recorded message, as well as visual diagrams to help understand it

With the recent detection of exoplanets, we have new results that show that some could be inhabited. Before 1995, we didn't know that there were so many exoplanets. And some of them, or at least one of them, is inhabited. It's one for the philosophical thinkers, too, because it's important to think about the philosophical viewpoint and not just the science viewpoint. In the meantime, METI is working on the contents of this message, which languages would be possible to be sent and so on.

Do you think it's a better idea to send messages in a physical form, for example Voyager's Golden Records, or as a radio signal like the Arecibo message?
I think radio signals are better because it's possible to send them to target planetary systems. We can send a lot of information with very simple technology. With our present technology, we're not able to do the same thing with physical messages.

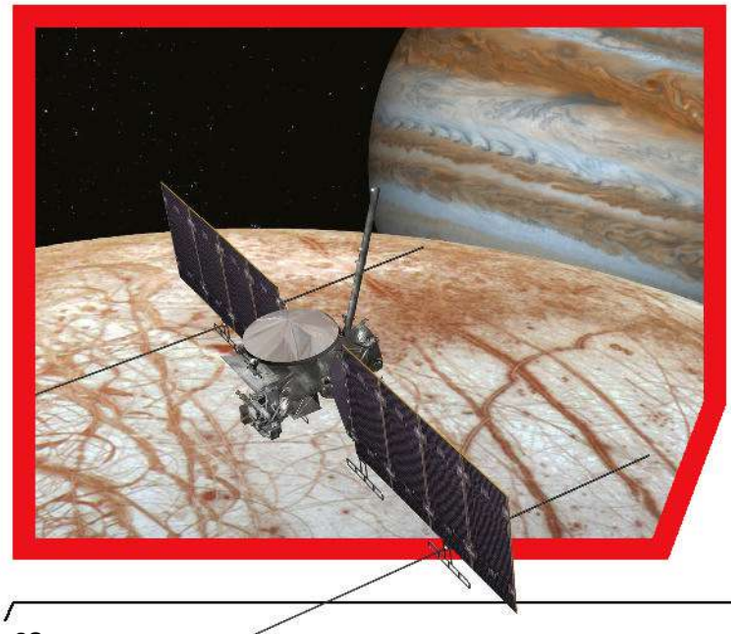
What's your stance on alien intelligence? Do you believe it's out there?
Yes, I believe it's possible, because as you know we have found many exoplanets. A lot of exoplanets have been discovered, and some of them could be like our Earth. Maybe life could be possible on some of these planets. So why would Earth be the only planet with inhabitants, even if it's very simple life? I think it's possible to have simple life on other planets – and why not on the ones we don't know about. We are looking, but we don't know. But my opinion is that it's possible because of the many discoveries of exoplanets. But life, of course, is not so easy to create. The birth of life on a planet is not so easy, so we don't know if it's an event that's very frequent or not.



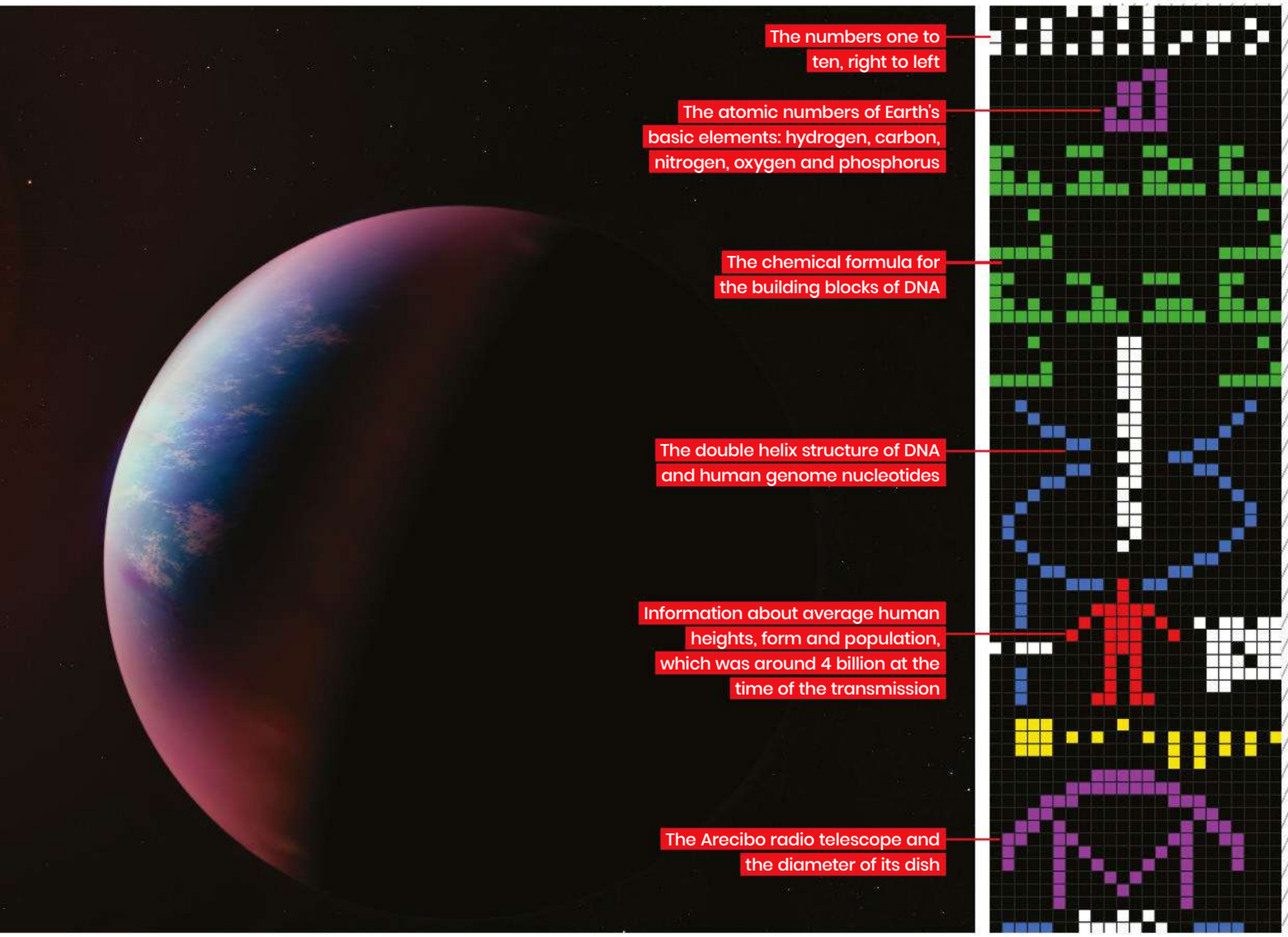
"A lot of exoplanets have been discovered, and some could be like our Earth. Maybe life could be possible on some of these planets"

Would it be possible for life to arise from non-carbon-based chemistry, unlike our own?
The usual thought surrounding that is that carbon is necessary to have some combination of atoms that are very efficient to build life. Life built on other atoms, for example, silicon, is not the usual hypothesis in the scientific community. So carbon seems to be necessary to build life on other planets too, like on Earth.

Why do you think we haven't seen life elsewhere in the universe yet?
Because it's difficult. In the Solar System there have been space exploration missions to find out if there is life on other planets. Until now, we haven't found any life. We are looking for past microbial life on Mars, because Mars may have had temperatures that were very good for life at the beginning of the life of this planet. But we just don't know. In fact, now there is no life on Mars, but maybe microbes could have emerged at the very beginning of the planet and now they are extinct. Astronomers are basically looking for microfossils. Microfossils are the next step in the exploration of Mars.



NASA's Europa Clipper mission will launch for Jupiter's moon in October 2024


The numbers one to ten, right to left
The atomic numbers of Earth's basic elements: hydrogen, carbon, nitrogen, oxygen and phosphorus
The chemical formula for the building blocks of DNA
The double helix structure of DNA and human genome nucleotides
Information about average human heights, form and population, which was around 4 billion at the time of the transmission
The Arecibo radio telescope and the diameter of its dish

What about other planets in the Solar System?
There could be evidence on other planets in the Solar System, maybe on the satellites around giant planets such as Jupiter or Saturn. There's the possibility of life in the oceans inside big moons like Europa because they have liquid water in their interiors. However, these hypotheses are really just speculation because we have no concrete evidence of life in another place in the Solar System. And far away? None.

On exoplanets it's even more difficult to detect life. We are too far away, so we have to detect non-direct evidence. We have to detect products of life such as biosignatures – compounds in the atmosphere. This is evidence for the product of exolife. We have to undergo spectroscopic analysis and other non-direct methods to detect life in other planetary systems.

In the Solar System, we can send probes to see if there's life. It's difficult, but it's simpler than exploring exoplanets, as they are too far away. We have to wait for biosignature detections around the planets and to detect special compounds, for example carbon compounds, which could be products of other life. It will soon be possible to detect this signature in exoplanet atmospheres with future telescopes. It's the next step for bioastronomy – people working on exoplanets and people looking for life elsewhere.

How do you see the future of METI and the search for extraterrestrial life going?
I think METI is very important because it's the first international organisation which is dealing with such topics. SETI is largely debated around the world, and in many countries, especially in the US with the SETI institute, but also in Europe, in the UK and in France. But METI is the first time where there is active collaboration, and I hope this organisation will be able to continue and to send a message in the future. This isn't the only aim of the organisation. As we showed in a METI workshop in Paris, France, it's to gather scientists, philosophers and sociologists to debate about topics such as the Fermi paradox or topics related to the Drake equation.

The Arecibo message, sent via radio signals, describes the human race in binary code

Astronomers examine an exoplanet's atmosphere by studying the starlight that passes through it

© Getty Images; NASA/JPL-Caltech

ULTRA-HARD DIAMONDS IN THE SKY

Scientists probing a set of space rocks have found lonsdaleite, and it's helping solve the mystery of how these rare diamonds are formed

Reported by David Crookes

A group of scientists are getting very excited about these ultra-hard diamonds. After all, they reckon they've found evidence of lonsdaleite having formed on a dwarf planet some 4.5 billion years ago, and the resulting study has the potential to be very useful indeed. Scientists have known about lonsdaleite for many years. It was first discovered in 1967 in a meteorite called Canyon Diablo, found in an impact crater in the desert of northern Arizona. Duly named after British crystallographer Dame Kathleen Lonsdale, one of the first two women elected a fellow of the Royal Society in 1945, it was soon determined to be a much harder form of diamond. Yet researchers weren't sure whether it was a defect of a regular diamond formed under intense pressure or if it actually existed in nature.

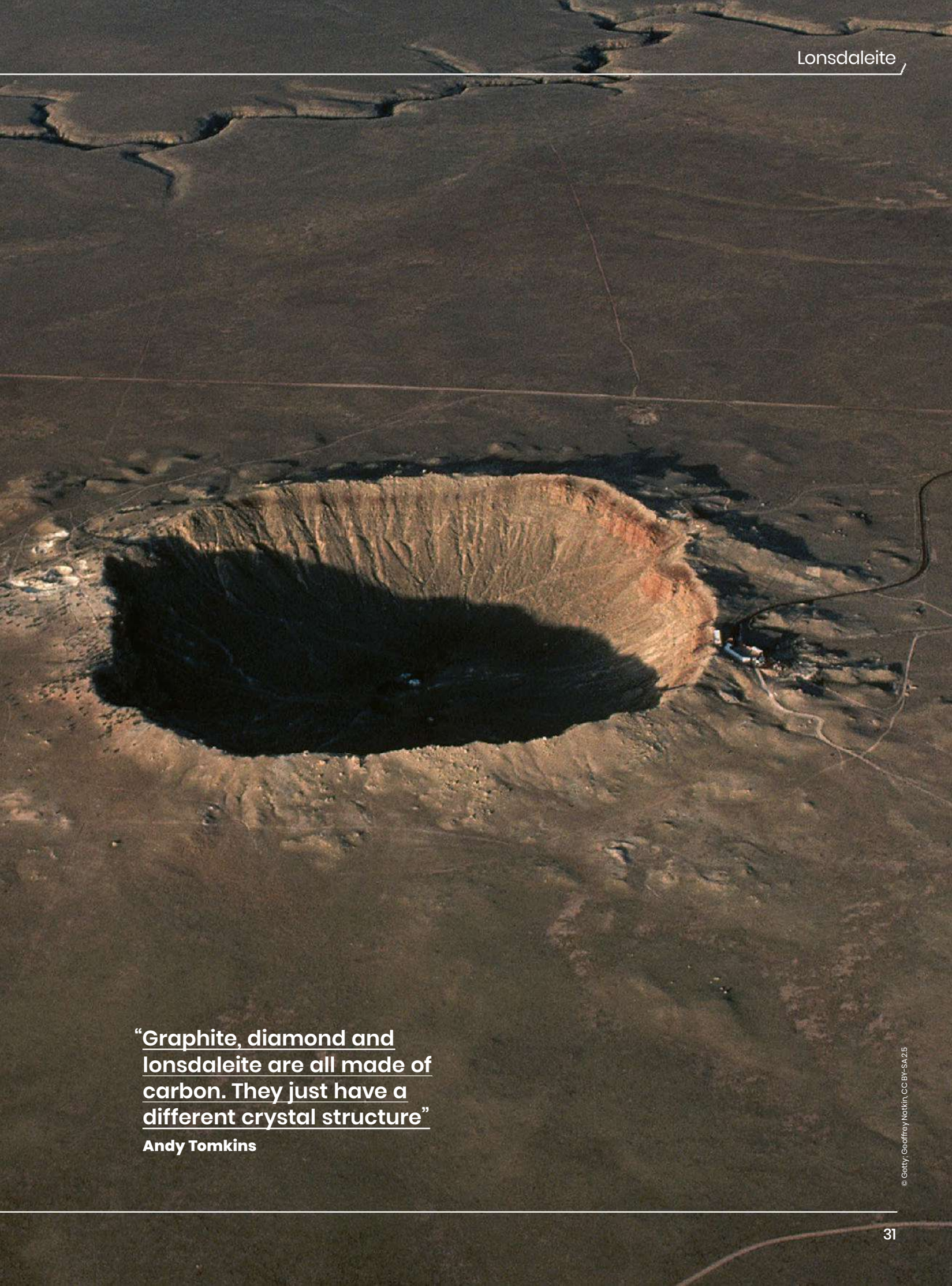
It was with such a mystery in mind that a group of Australian scientists from Monash University and RMIT University got to work. They began to study 18 diamond-bearing meteorite samples collected mostly from western Africa, with one coming from Australia. In particular, they were looking for signs of carbon atoms arranged in a three-dimensional hexagonal structure – the very thing that sets lonsdaleite apart from the cubic atomic structure of a regular diamond. It also sets lonsdaleite apart from graphite, which boasts a two-dimensional hexagonal structure.

"Graphite, diamond and lonsdaleite are all made of carbon. They just have a different crystal structure," affirms Professor Andy Tomkins, team leader and a geologist at Monash University in Melbourne. "Diamond has a cubic structure, graphite consists of sheets of flat hexagons and lonsdaleite has a three-dimensional hexagonal structure." To the scientists' great delight, they found what they were looking for, and it's since enabled them to make a huge breakthrough.

Key to the study is where the lonsdaleite was found. The meteorites being studied by the Australian researchers were of a rare class of space rock called ureilites – so-called because such meteorites were first found in the village of Novy Urey in the Mordovia Republic of Russia in 1886. Ureilites have long been known to be rich in carbon, manifesting in the form of graphite and diamond. Indeed, ureilite meteorites contain greater abundances of diamond than any known rock, says Tomkins, but finding lonsdaleite as well has given strong pointers as to how the latter has been able to form.

To find and analyse the lonsdaleite, scientists made use of advanced electron microscopy techniques. They were able to capture solid and intact slices from the

The Canyon Diablo meteorite was discovered in Barringer Crater in Arizona, but only contained minute traces of lonsdaleite



"Graphite, diamond and lonsdaleite are all made of carbon. They just have a different crystal structure"

Andy Tomkins

© Getty: Geoffrey Notkin, CC BY-SA 2.5

THREE POTENTIAL EXPLANATIONS

Scientists have considered how lonsdaleite forms

Forming under high pressure

Lonsdaleite can form over billions of years when there are high pressures and temperatures. In 2020, however, scientists in Australia also created lonsdaleite in a lab by applying high pressures of 100 gigapascals at normal room temperature.

Shock caused by a collision

When a graphite-bearing meteorite collides with Earth, it causes a high-energy shock wave. In theory, this converts graphite into small diamonds while retaining the graphite's hexagonal structure, making lonsdaleite a potential defected diamond.

It occurs naturally in ureilites

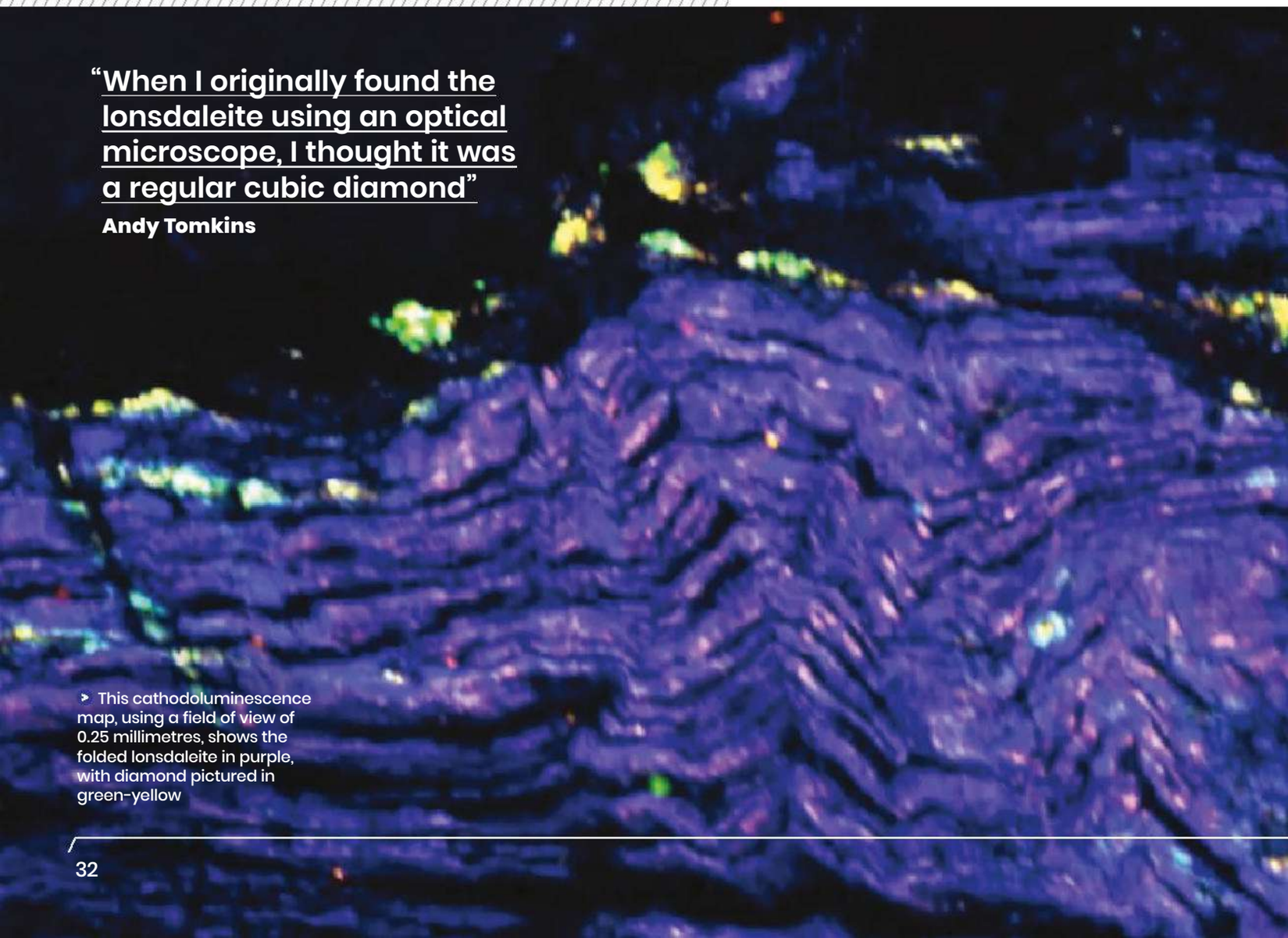
According to the study by Tomkins, lonsdaleite has been found in ureilite meteorites formed in the mantle of a dwarf planet 4.5 billion years ago. Graphite on the planet was turned into lonsdaleite thanks to a chemical reaction sparked by an asteroid collision.

meteorites and peer at their crystal structures, allowing them to map the relative distribution of lonsdaleite, graphite and diamond and see how the rocks formed.

"When I originally found the lonsdaleite using an optical microscope, I thought it was a regular cubic diamond," says Tomkins, who had noticed an odd-looking diamond in a space rock when categorising meteorites. "But while there is a fair bit of cubic diamond in the samples as well, by using cathodoluminescence imaging with an electron microprobe, we first got the hint that it might be lonsdaleite. We then confirmed the hexagonal crystal structure of lonsdaleite using a transmission electron microscope."

This proved crucial. Up until this point, lonsdaleite had only ever been found in impact craters, and such exclusivity meant lonsdaleite had become an indicator of ancient asteroidal impacts on Earth. As noted by Arizona State University in 2014, pure lonsdaleite crystals – no matter how small – had never been found or synthesised, and it was thought that shock or pressure had been causing defects within the crystal structure of the regular cubic form of diamond.

Yet the work carried out by Tomkins and the wider research team has turned such thinking on its head, pointing towards lonsdaleite formation by a different



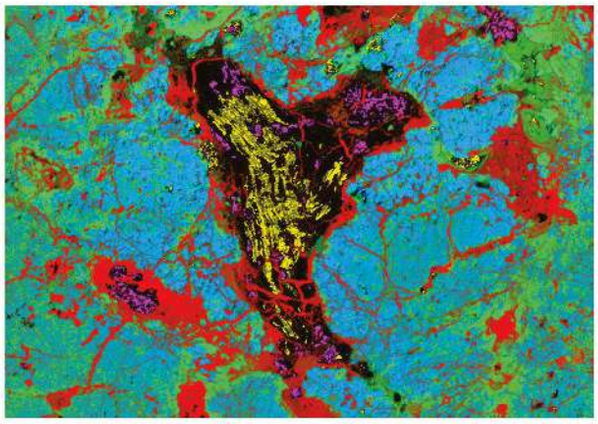
"When I originally found the lonsdaleite using an optical microscope, I thought it was a regular cubic diamond"

Andy Tomkins

This cathodoluminescence map, using a field of view of 0.25 millimetres, shows the folded lonsdaleite in purple, with diamond pictured in green-yellow

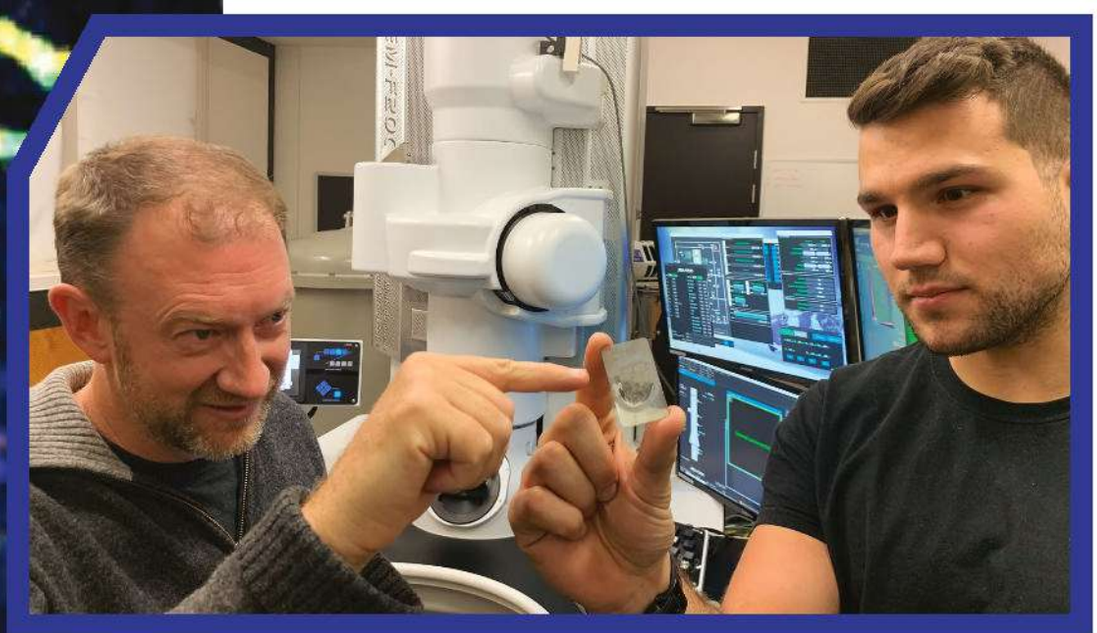
process entirely. "It was recognising that there was a progression in mineral formation from graphite to lonsdaleite to diamond plus graphite, and that gave us a unique insight into how the minerals had formed," Tomkins explains. "In a few examples we saw a vein of diamond cutting across lonsdaleite, which is pretty unique, and probably requires involvement of a fluid or gas in the formation process." In other words, not only had the researchers found lonsdaleite somewhere other than within an impact crater, they also had some clues as to how it formed and from where it came.

First of all, we can rule out Earth as an origin. "The samples are meteorites, so the lonsdaleite and diamond couldn't have formed on Earth," Tomkins affirms. Many scientists also accept that ureilite meteorites contain material from the mantle of dwarf planets. "This theory has been figured out by other people, largely," Tomkins says. "Many other scientists have established that the ureilite meteorites come from the mantle of a large asteroid; there is a question of just how big it was that has proven difficult to resolve."



As such, Tomkins and the other researchers on the team believe the rocks they were studying had formed in the mantle of a dwarf planet, and well before they ended up being transported to Earth within meteorites. It would appear that they were modified when an asteroid collided during the early formation of the Solar System, dating back about 4.5 billion years. The impact of this was so great that it destroyed the dwarf planet. But here's the thing: lonsdaleite, according to the researchers, doesn't appear to have been created by the impact causing a defect in a regular cubic diamond, as appears to be the case when lonsdaleite has been produced on Earth. Instead it seems there was a chemical reaction and that a supercritical fluid turned the preexisting graphite into lonsdaleite as pressure decreased when the asteroid was disrupted.

Here you can see the inside of a meteor as detected by electron probe analysis. Lonsdaleite is coloured yellow. The pink areas are diamond, red is iron, magnesium is blue and silicon is green



Tomkins studying a ureilite meteor sample with PhD scholar Alan Salek

© PNAS; RMIT University; Nick Wilson

LONSDALEITE BY NUMBERS

ONE TO TWO
Size of the lonsdaleite discovered in 1967

ONE MICROMETRE
Size of the most recent discovery of lonsdaleite

1,000
times larger than the original find

58%
harder than regular diamonds

18
meteorite samples from ureilites were examined

4.5
years ago, lonsdaleite within them may have formed on a dwarf planet

50,000
years ago, a meteor impact in Arizona, in which Lonsdaleite has also been found, occurred

In fact, as Tomkins' fellow researcher Dougal McCulloch of RMIT has said, it's likely there was a "supercritical chemical vapour deposition process" within the space rocks. "Chemical vapour deposition is one of the ways that people make diamonds in the lab, essentially by growing them in a specialised chamber," he explains. Once the pressure decreased and there was environmental cooling, diamond partially replaced some of the lonsdaleite. "We think graphite crystals formed as the ureilite parent asteroid grew and partially melted," Tomkins says. "This early stage is when the asteroid differentiated into core, mantle and crust – with crystal growth in the mantle deforming the graphite crystals, creating folded flakes. Then there was a catastrophic collision with another asteroid that destroyed much of the ureilite parent asteroid. This caused decompression after the collision, within the fragments and in the remaining mantle. This decompression promoted fluid and gas release, which then reacted with the rock, forming the ideal fluid-gas chemistry for lonsdaleite formation. Lonsdaleite replaced the folded graphite flakes, preserving their shape almost perfectly in some cases. As conditions cooled further, diamond plus graphite partially replaced lonsdaleite."

Such findings confirm the existence of lonsdaleite. More than that, the study – which has been published in the *Proceedings of the National Academy of Sciences* and also involved scientists from the Commonwealth Scientific and Industrial Research Organisation, the Australian Synchrotron and Plymouth University in the UK – proves that lonsdaleite exists in nature as a material in its own right. It also takes scientists a step closer to being able to replicate the process and create lonsdaleite in a laboratory, just as they can with diamonds. Since lonsdaleite is incredibly strong – lonsdaleite is thought to be 58 per cent harder than diamond because of its three-dimensional hexagonal lattice – this is a big deal.

After all, diamonds are not simply pretty objects to place within rings or other forms of jewellery. Diamonds are also used across multiple industries. You'll find them on saws that are capable of slicing into roads, on the tip of a record player's needle and even in medicine – nanodiamonds could help us better understand how cancer develops in our cells. And here we have the finest diamond of them all. While we don't know how sparkly or colourful lonsdaleite would be when worn, we do know that it could have many uses. If it can be created in a lab, lonsdaleite's uncommon structure could be used to develop ultra-hard materials such as machine parts.

It could be used for more advanced saw blades or even in the process of cutting regular diamonds. Now that this discovery has been made, efforts will certainly be underway to develop new manufacturing techniques, and the results could be revolutionary. There's a chance that, one day, you could wear a lonsdaleite ring on your finger. It would be hard-wearing, that's for sure. "The research is important because

HOW LONSDALEITE FORMED NATURALLY

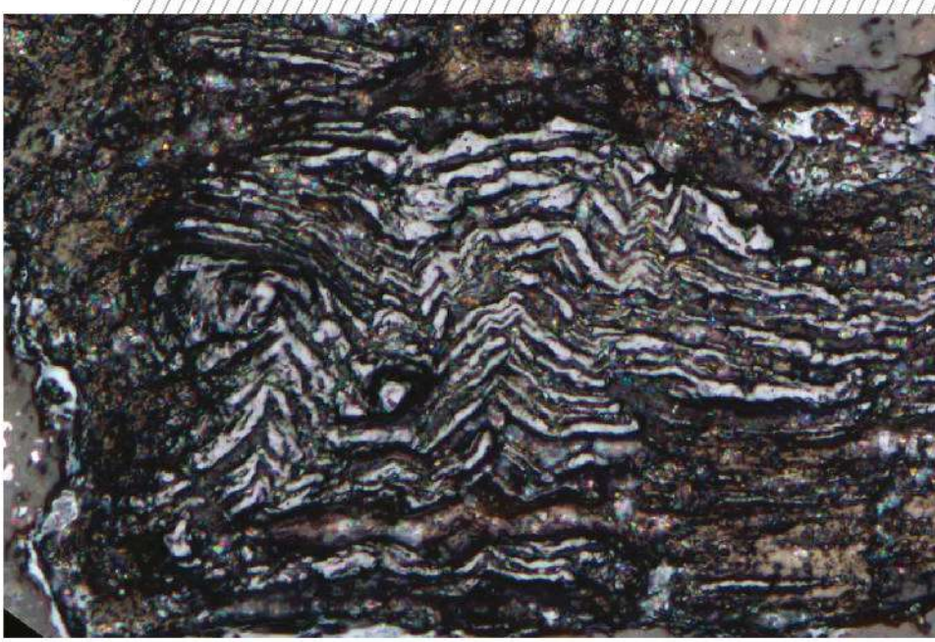
A look at how this ultra-hard diamond emerged in a meteorite

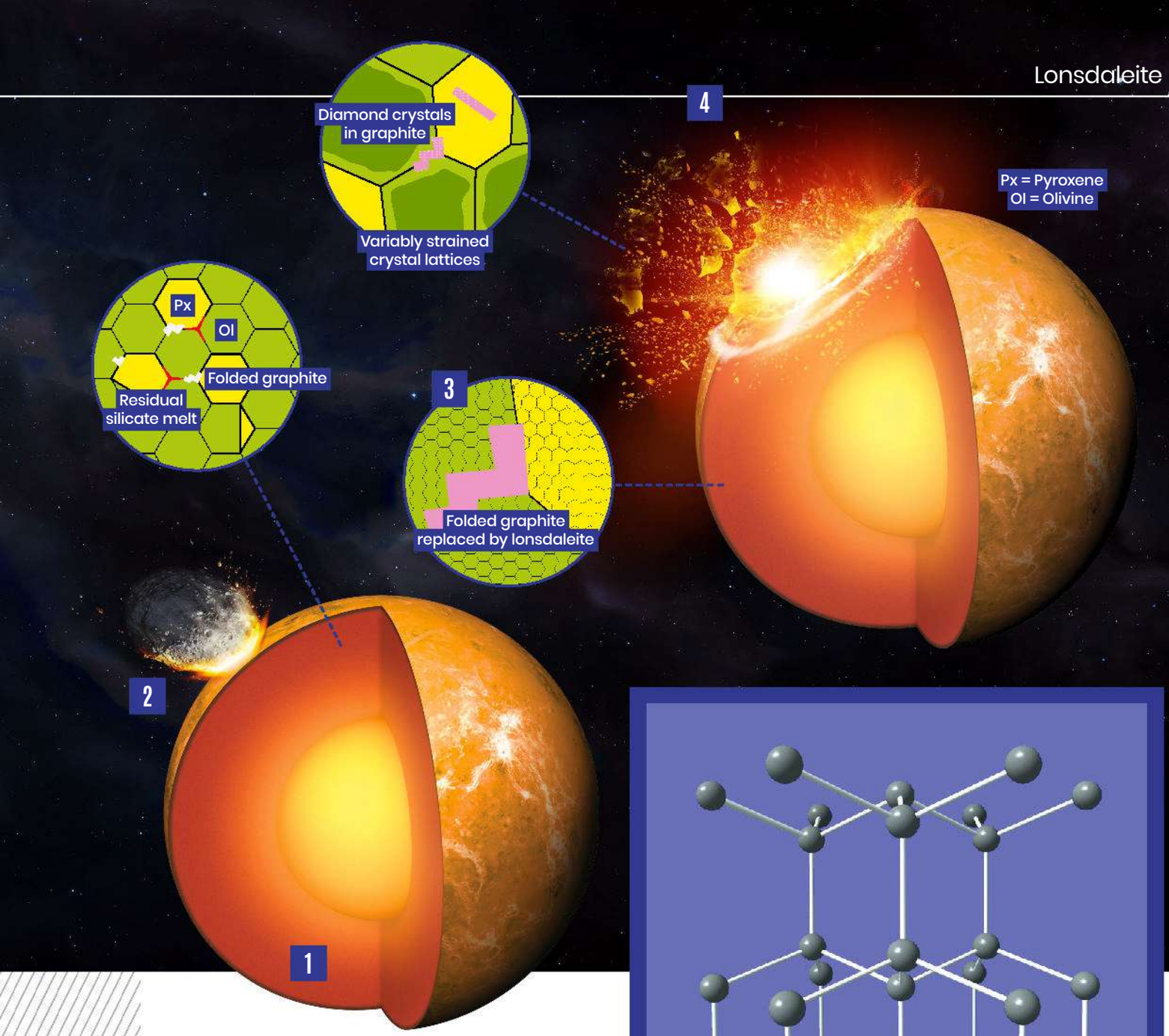
1 Mantle formation
High temperatures in a dwarf planet's mantle caused a fluid mix of carbon, hydrogen, oxygen and sulphur to become heated and pressurised.

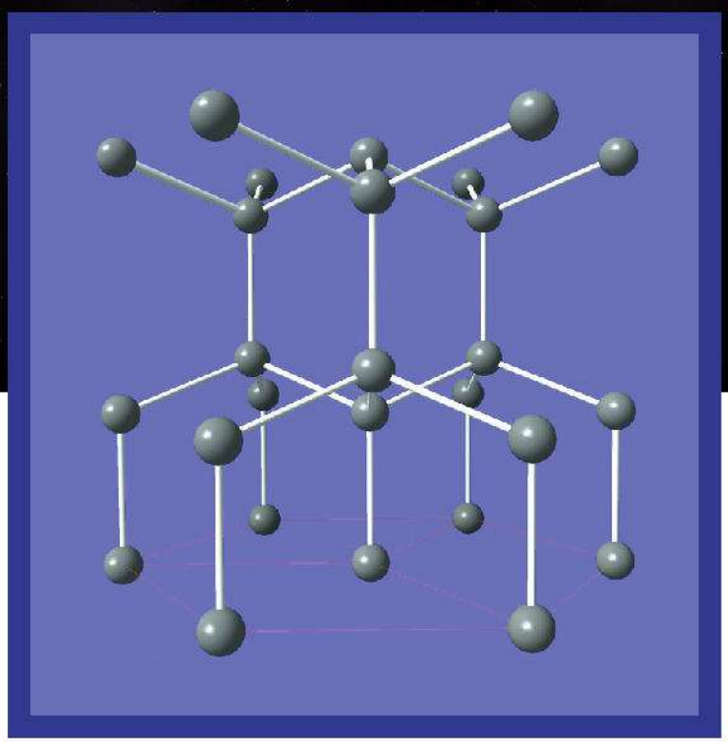
2 A collision
An asteroid impact smashed the mantle – an event taking place about 4.5 billion years ago. Pressure and temperature dropped in the immediate aftermath.

3 Mixing with graphite
As the chemical mix was released, it interacted with the graphite crystals and caused them to be replaced by lonsdaleite.

4 To Earth
Ureilites – meteorites thought to have originated in the mantle of a dwarf planet – came to Earth, where they were later found and examined.







it improves our understanding of how the hardest minerals known form," Tomkins says. "If we can replicate the lonsdaleite-forming process, we can make shaped, ultra-hard, micro machine components. There would be numerous applications if we or somebody else can develop the technology."

Such a step, however, is still a little way off. It would involve exactly recreating the conditions needed for lonsdaleite to form, and that will mean getting the correct chemical mix in tandem with the right amount of pressure and high temperature. There's also the little matter of cost – who knows how expensive it would be to begin replicating lonsdaleite for industry, although it could prove cost-effective in some ways.

But it's nevertheless encouraging. The lonsdaleite crystals discovered in the latest research are the largest ever discovered, and while they're far thinner than a human hair given they are only up to a micron in size, the study remains significant, especially given the efforts in recent years to make a crystal harder than diamond. As it turns out, space has sent a wonderful gift our way, and it would seem scientists are very grateful for it. If diamonds are a girl's best friend, then lonsdaleite may well be a scientist's lifelong partner.

David Crookes
Science and tech journalist
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.

The crystal structure of lonsdaleite is hexagonal, which is different to the cubic arrangement of diamonds

This microscope image shows the folds of polycrystalline lonsdaleite made from many tiny crystals

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MOON PROFILE

CHARON

The secrets of Pluto's largest moon

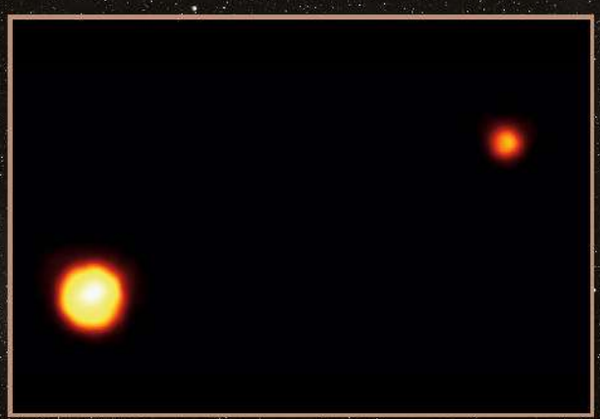
Nobody knew it was there until 1978. For almost 50 years after Pluto's discovery in 1930, the dwarf planet had no known companions out on the edge of the Solar System. Today, though, in the wake of the New Horizons mission and a myriad of discoveries since the first inklings of the Kuiper Belt came in 1992, we know it positively teems out there. Charon is one of a system of five moons, and Pluto is the second-largest of a huge collection of objects orbiting beyond Neptune. The ongoing hunt for a large planet in the extreme reaches of the Solar System has so far come to nothing; this is the domain of the small, with Pluto's reclassification as a dwarf planet just the first in a whole raft of triumphantly tiny accolades.

Pluto's largest moon, however, has some remarkable features of its own, despite only having a diameter of 1,212 kilometres (753 miles) – about 10.5 per cent that of Earth's. One-eighth the mass of its host Pluto and half the diameter, it's tidally locked to the larger body, but large enough that the two orbit a common centre of mass between them. The International Astronomical Union's general assembly considered a proposal in 2006 to reclassify the pair as a double planet, but despite it being spherical, it wasn't clear Charon was in hydrostatic equilibrium, a state in which the force of gravity is balanced by outward pressure from the body. This state is necessary to give it dwarf planet status.

Charon's name – pronounced with a hard 'K' sound at the beginning – which it shares with the ferryman who takes souls over the River Styx to Hades in Greek mythology, where they're guarded by the three-headed dog Cerberus, comes from its discoverer James W. Christy, whose wife was named Charlene – he pronounces Charon with a 'sh' sound, as does the New Horizons team. However, a 1967 novel by Edmond Hamilton, *Calling Captain Future*, names three Plutonian moons as Charon, Styx and Cerberus. Whatever the origin, the name was officially announced in January 1986, replacing the temporary designation S/1978 P 1. As more moons were discovered around Pluto, they were named Styx; Nix, after the Greek goddess of the night; Kerberos – Cerberus was already taken by an asteroid – and Hydra, a nine-headed water monster.

Charon orbits so close to Pluto that when examining photographic plates of the erstwhile planet taken using the 1.55-metre (61-inch) telescope at the United States Naval Observatory Flagstaff Station, all Christy saw was a bulge in the shape of the tiny disc. By revolving around the disc with time, it revealed itself to be a moon. It wasn't until the development of adaptive optics for Earth-based telescopes that it became possible to resolve the pair as separate discs. The bodies whip around each other once every 6.4 days at an average distance of 19,640 kilometres (12,203 miles) and take 248 years to complete a trip around the Sun.

We had to wait until the New Horizons probe entered the system in 2015 to get a really good look at Charon. A largely grey world of rock and water ice with a reddish cap at its north pole, it remains a fascinating part of the Solar System, with more secrets to be discovered.



Charon is half the size of its parent body, the dwarf planet Pluto

Moon composition

55%
Rock

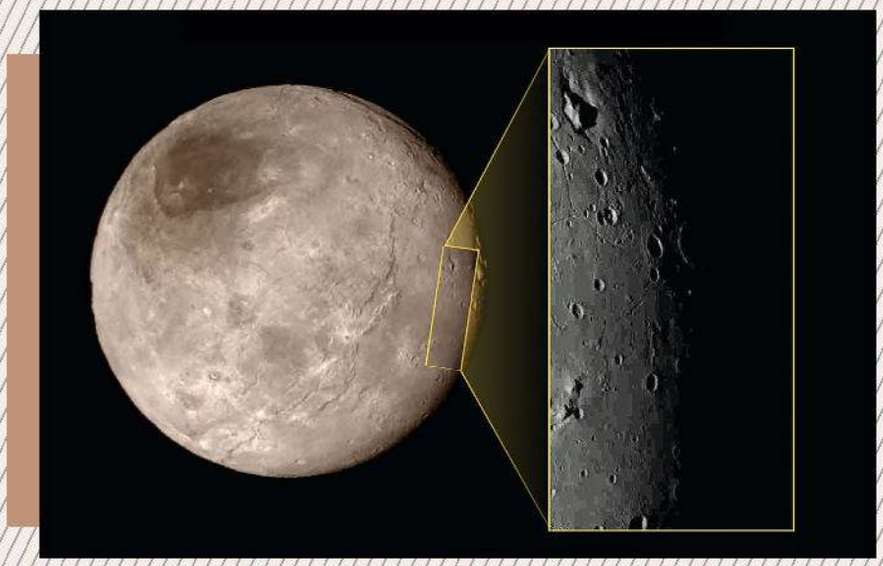
45%
Ice

© NASA/ESA/ESO

NEWS FROM CHARON

Fantasy features

Various features on the surface of Charon have been given official names by the International Astronomical Union Working Group for Planetary System Nomenclature. The names reflect travellers and explorers, especially those with mysterious destinations. Dorothy crater, for example, is named after the protagonist from *The Wizard of Oz*, while Caleuche Chasma is named for the mythological ghost ship that travels the seas around the small island of Chiloé off the coast of Chile. Mandjet Chasma is named for one of the boats in Egyptian mythology that carried the Sun god Ra across the sky each day, and Nemo crater honours the captain of the Nautilus, the submarine in Jules Verne's novels.

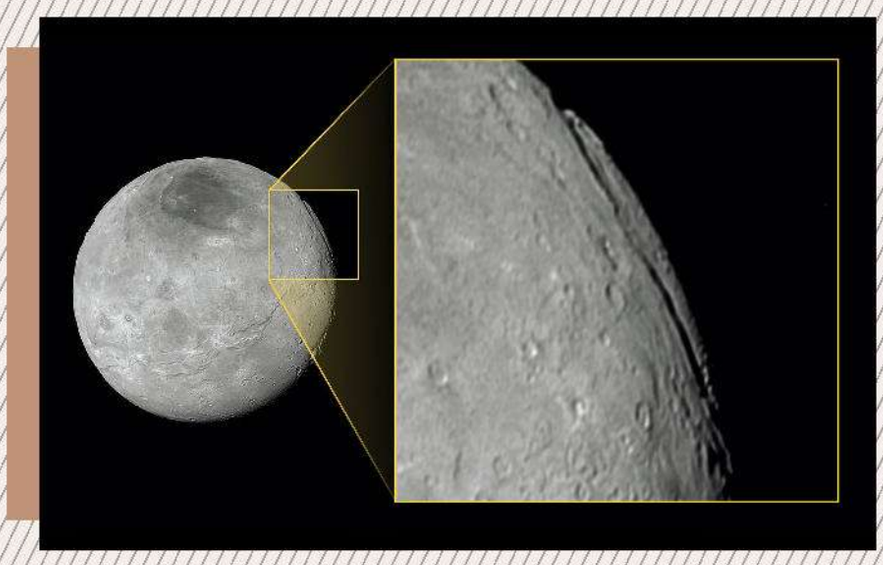


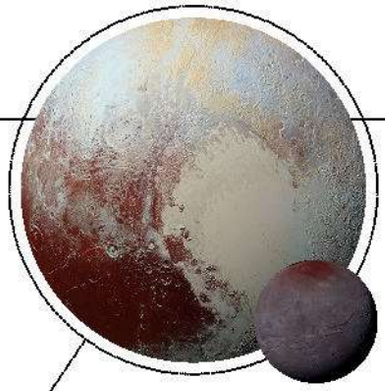
What's in the cap?

Charon's north polar cap is different to the rest of its surface, and Pluto may be sharing its atmosphere with its largest moon. A study from Lowell Observatory in Arizona modelled conditions on Charon over the past few billion years and discovered that radiation had been stripping the hydrogen from frozen methane on the dwarf planet's surface. This left behind carbon, which joined with other molecules to make heavier materials more able to stick to the surface rather than be lost to space. These became organic molecules called tholins, which produce the red hue. There was speculation after New Horizons revealed Charon's red pole that the cap was enriched with tholins, which could have gotten there via atmosphere transfer.

Maps made

New Horizons did more than take photos when it passed through the system in 2015. The wealth of data it sent back is still being analysed years after the probe moved deeper into the Kuiper Belt. New Horizons only directly imaged 45 per cent of the surface in daylight, meaning there are still secrets left to uncover, but by stitching together images from a pair of New Horizons' cameras, a team from the Lunar and Planetary Institute in Texas was able to create a height map of the surveyed areas. From this, the size of surface features could be calculated, including the six-kilometre (3.7-mile) high Tenzing Montes, the moon's highest mountain range.





THE EVOLUTION OF CHARON

Date: 4.5 billion years ago
Activity: Two Kuiper Belt objects collided, going into orbit around a shared barycentre.

Date: 1930
Activity: Discovery of Pluto by Clyde Tombaugh.

Date: 1978
Activity: Discovery of Charon by James Christy.

Date: 1980s
Activity: Pluto and Charon eclipsed one another several times, allowing astronomers to study their spectra and work out their surface compositions.

Date: 1994
Activity: Hubble imaged Pluto and Charon from 4.4 billion kilometres (2.7 billion miles) away.

Date: 2007
Activity: Observations by the Gemini Observatory suggested active cryogeysers on Charon's surface.

Date: 2015
Activity: New Horizons arrived in the system, gathered data and then left.

Date: 2017
Activity: NASA's Ames Research Center confirmed Charon once had active plate tectonics like Earth.

Date: 2019
Activity: A geomorphological map of Charon's surface was published, dividing the surface into 16 types.

CHARON BY NUMBERS

19,640 KILOMETRES
The average distance between Charon and Pluto

-213°C
Summer temperature in Charon's north polar region

40 KILOMETRES
Diameter of Kubrick Mons, a strange mountain in a moat on Charon

-258°C
Winter temperature in Charon's north polar region

6 KILOMETRES
Height of Tenzing Montes, Charon's highest peaks

14 KILOMETRES
The depth of Charon's Caleuche Chasma; it's roughly seven times deeper than the Grand Canyon

FUTURE EXPLORATION OF CHARON

New Horizons passed through the Pluto system without stopping and is continuing to speed through the Kuiper Belt on its way out of the Solar System as one of the fastest human-made objects ever launched. Another probe could hypothetically spend much more time investigating Pluto and its moons, using Charon as a source of momentum.

The mission – which is purely theoretical at this point, having been demonstrated by New Horizons' software lead Tiffany Finley – could explore each of the moons in the Pluto system, passing each at least five times and returning to Charon after each one for a course-correcting gravity assist. Using an electric propulsion system similar to that on the Dawn mission to Vesta and Ceres, the tour would only use fuel for 'clean-up manoeuvres' designed to make sure it was going in exactly the right direction, making it an efficient way to visit the moons. The Cassini probe did something similar using Titan while touring the moons of Saturn.

The mission could even be extended so that with one final gravity assist the probe would enter the Kuiper Belt and enter orbit around a second dwarf planet. New Horizons' visit to Pluto was a big success, but it was necessarily limited by the speed at which it passed the system. A second probe spending more time there would perhaps be able to answer many of the remaining questions about Pluto, Charon and its scattering of small moons.

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50 AMAZING FACTS ABOUT BLACK HOLES

Few things are as universally awe-inspiring and terrifying as black holes. These invisible behemoths are the great architects and the great destroyers of the universe

Written by Laura Mears

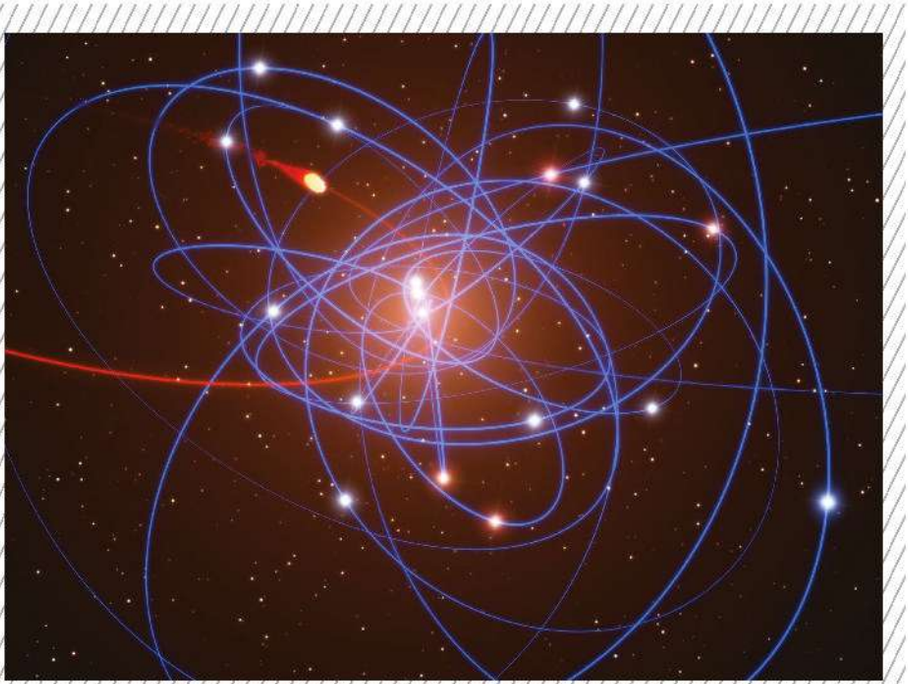
1 MANY BLACK HOLES STARTED LIFE AS STARS

"As stars age, the fuel eventually starts to run out"

Stars spend their entire lifetimes resisting gravitational collapse. Their enormous masses mean that their gas is continually pulled towards their cores, but instead of collapsing down, atoms collide and fuse, releasing explosive atomic energy. Radiation pushes outwards against gravity, holding the star open as a glowing ball of gas. As stars age, more and more of the atoms are fused, creating heavier and heavier elements, and eventually the fuel starts to run out. Without the outwards push, the balance is tipped in favour of gravity and the star begins to collapse. For small stars, such as the Sun, the collapse is incomplete, and repelling forces manage to hold the last glowing embers open as a white dwarf star. For a white dwarf star that's larger than 1.4 times the mass of the Sun – known as the Chandrasekhar limit – these forces are insufficient. The star continues to crunch inwards, forming a dense neutron star or a black hole.

2 SUPERMASSIVE BLACK HOLES DON'T DESTROY EVERYTHING NEARBY

Actively feeding supermassive black holes are some of the most violent places in the universe, and quasars devour the equivalent of tens to thousands of Suns each year. Amazingly, though, the galaxies that surround them don't disappear into the abyss. Despite their frightening reputation, black holes don't actually behave that differently to other massive objects in the universe, unless you get too close. Just as Earth will not spontaneously crash into the Sun, objects in stable orbits around black holes are in no danger of being swallowed.



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3 BLACK HOLES SLOW THE FLOW OF TIME

To an outside observer, an object falling into a black hole appears to slow down before stopping, caught in suspended animation at the boundary.

4 A BLACK HOLE REVEALS NO CLUES ABOUT WHAT IT'S SWALLOWED

As matter enters a black hole, it's stretched, pulled and eventually shredded. Even if something were to leak out, it would bear no resemblance to what went in.

5 THEY HAVE NO SIZE LIMIT

In theory, black holes continue to grow in size indefinitely, but just how large they are able to get depends on their local environment.

6 AROUND THE SAME MASS AS THE SOLAR SYSTEM

Supermassive black holes contain the mass of at least 100,000 Suns compressed into a space that's around the same size as our Solar System.

7 IT'S THE SIZE OF A BLACK HOLE THAT MATTERS, NOT ITS MASS

Just a few micrograms of matter would be enough to create a black hole if it were compressed into a small enough space.

8 SOME GALAXIES MIGHT HARBOUR ULTRAMASSIVE ONES

The galaxy OJ 287 has two black holes, one of which is thought to contain the mass of around 18 billion Suns.

9 BLACK HOLES FEED ON STARS, REVEALING THEIR LOCATIONS

Black holes cannot be seen directly, but the effect they have on their surroundings often reveals their presence. In the Cygnus constellation, a blue supergiant star is being pulled into a teardrop shape, causing its light to flicker as it spins. The star orbits once every 5.6 days, and as it turns, the outer layer of gas is stripped away from its surface at 1,500 kilometres (932 miles) per second as it's funnelled to an invisible point.

The supergiant is part of a binary system and is locked in a fatal dance with a black hole known as Cygnus X-1. As the black hole spins, space and time spiral up with it, and dust and gas from the star accumulate in a vast swirling whirlpool known as the accretion disc. Particles spiral towards the event horizon, like water circling a drain, and as they tumble inwards the friction releases bright flashes and flares of X-ray light.

1

10 BLACK HOLES SPIN FASTER THAN THE STARS THAT MADE THEM

If a star is spinning when it dies, it will continue to spin if it becomes a black hole. However, it won't spin at the same speed. Imagine the star is a twirling ice skater, holding their arms outstretched. As they spin, they pull their arms inwards and start to spin faster. This is down to the law of conservation of angular momentum. As the matter collapses in towards the centre of a dying star, its diameter decreases – like the ice skater, it spins faster.

1 Companion star
Some stellar black holes are part of binary systems and are closely associated with another star.

2 Magnetic field lines
As black holes spin, the magnetic fields within their accretion discs will spiral up and down, creating a doughnut-shaped field around them.

3 Jets
At the poles of a spinning black hole, the magnetic field funnels material away from the immense gravitational pull, shooting it out into space in bright jets.

4 Event horizon
The event horizon is the point of no return, where the velocity required to escape the pull of the black hole is greater than the speed of light.

5 Accretion disc
Spinning black holes trap a wide disc of matter that increases in velocity towards the event horizon. Particles rub against each other, glowing with energetic radiation.

6 Singularity
Shielded from view at the very heart of the black hole, matter is crushed to a single point. Physics as we know it falls apart, and space and time cease to exist.

11 THE CENTRE OF A BLACK HOLE COULD CONTAIN A SINGULARITY

The event horizon of a black hole can measure thousands of kilometres in diameter, but once matter crosses over the edge, it doesn't stop moving. Exactly what happens on the inside is debated, but according to Einstein's theory of general relativity, the curvature of space-time inside a black hole is extreme, and everything is directed towards a single point, known mathematically as a singularity. Every possible path leads back to the centre, and matter becomes so crushed into such a tiny space that it's unrecognisable. The singularity is infinitely small and infinitely dense, creating an infinite curvature in space-time. Within a region of space known as the event horizon, anything that crosses over is compelled towards the centre with no hope of escape.

12 SOME OF THEM HAVE JETS

Some black holes spew impressive amounts of energy from their poles, marking their location like a beacon. As dust and gas race towards the event horizon of a spinning black hole, magnetic field lines direct some of the energy outwards, funnelling it into two energetic jets, like a particle accelerator.

NASA's Wide-field Infrared Survey Explorer (WISE) identified a pair of black holes orbiting one another that together create gravitational and magnetic disturbances so intense that their jets are being warped and twisted into ribbon-like spirals.

13 THEY LEAK RADIATION

Stephen Hawking showed that black holes could actually radiate energy, known as Hawking radiation, releasing their scrambled contents back into the universe.

14 IT TAKES MILLIONS OF YEARS TO ORBIT OUR SUPERMASSIVE BLACK HOLE

Sagittarius A* lies around 26,000 light years from the Solar System. It takes 225 million years for us to complete a single orbit around the galactic centre of the Milky Way.

15 THEY WERE KNOWN AS DARK STARS

The idea of black holes has been around much longer than the science that predicts their existence, but in the 18th century they were known as 'dark stars'.

16 CYGNUS X-1 WAS THE VERY FIRST BLACK HOLE TO BE IDENTIFIED

Cygnus X-1 is one of the brightest radio sources in the sky and is currently in the process of devouring a blue supergiant.

17 THEY CREATE WAVES

Einstein predicted that as massive objects like black holes move through space, they create gravitational waves that ripple through space-time, now confirmed.

18 THE UNIVERSE IS SHAPED BY THEM

Supermassive black holes are found at the hearts of almost all large galaxies and act as the linchpins of the universe around which stars and planets turn.

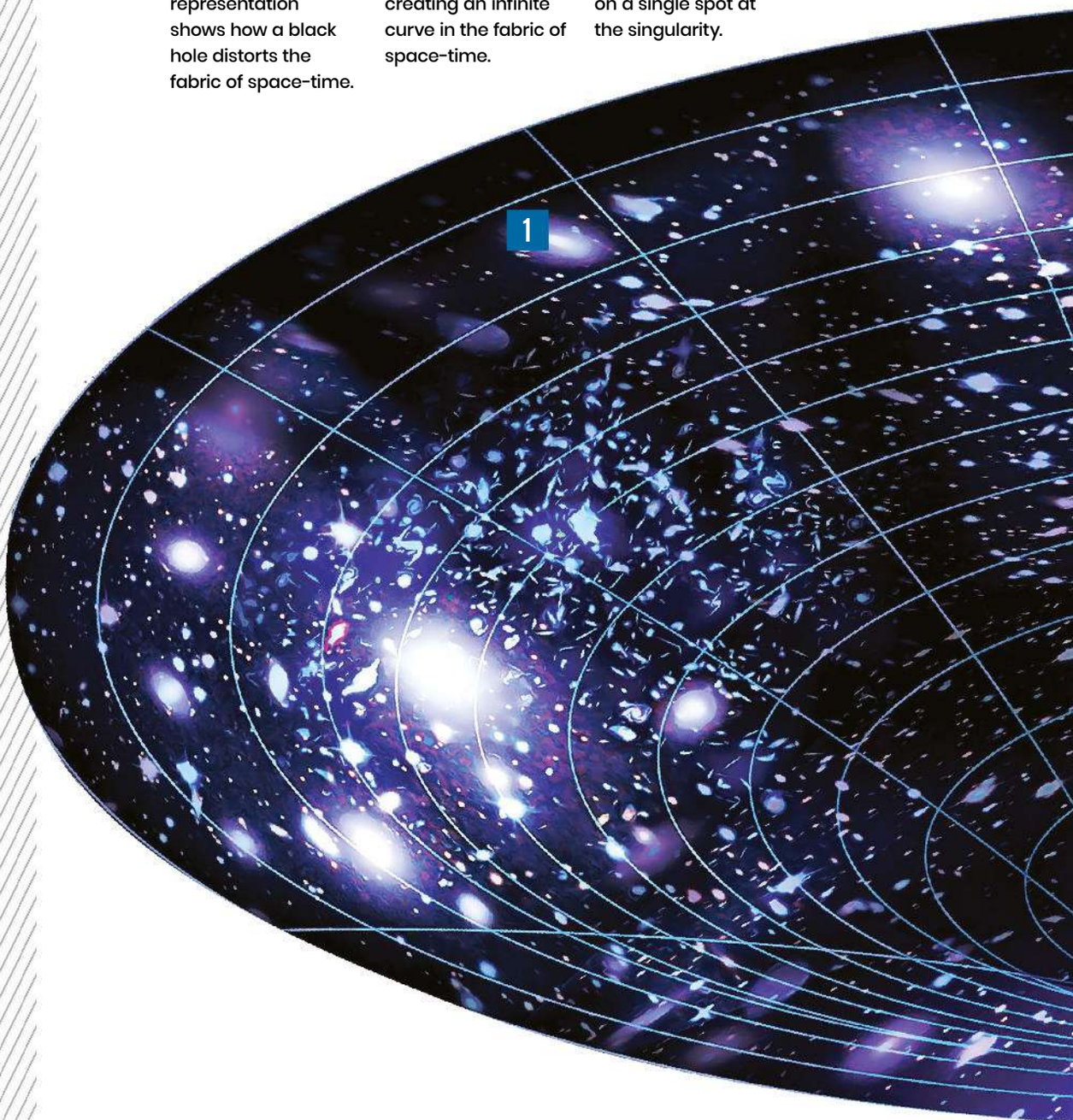
19 STELLAR BLACK HOLES CONTAIN THE MASSES OF FIVE OR MORE SUNS

Black holes formed during the death of a star usually contain at least as much mass as five Sun-sized stars, compressed into an area measuring just a few kilometres across.

1 Space-time
This two-dimensional representation shows how a black hole distorts the fabric of space-time.

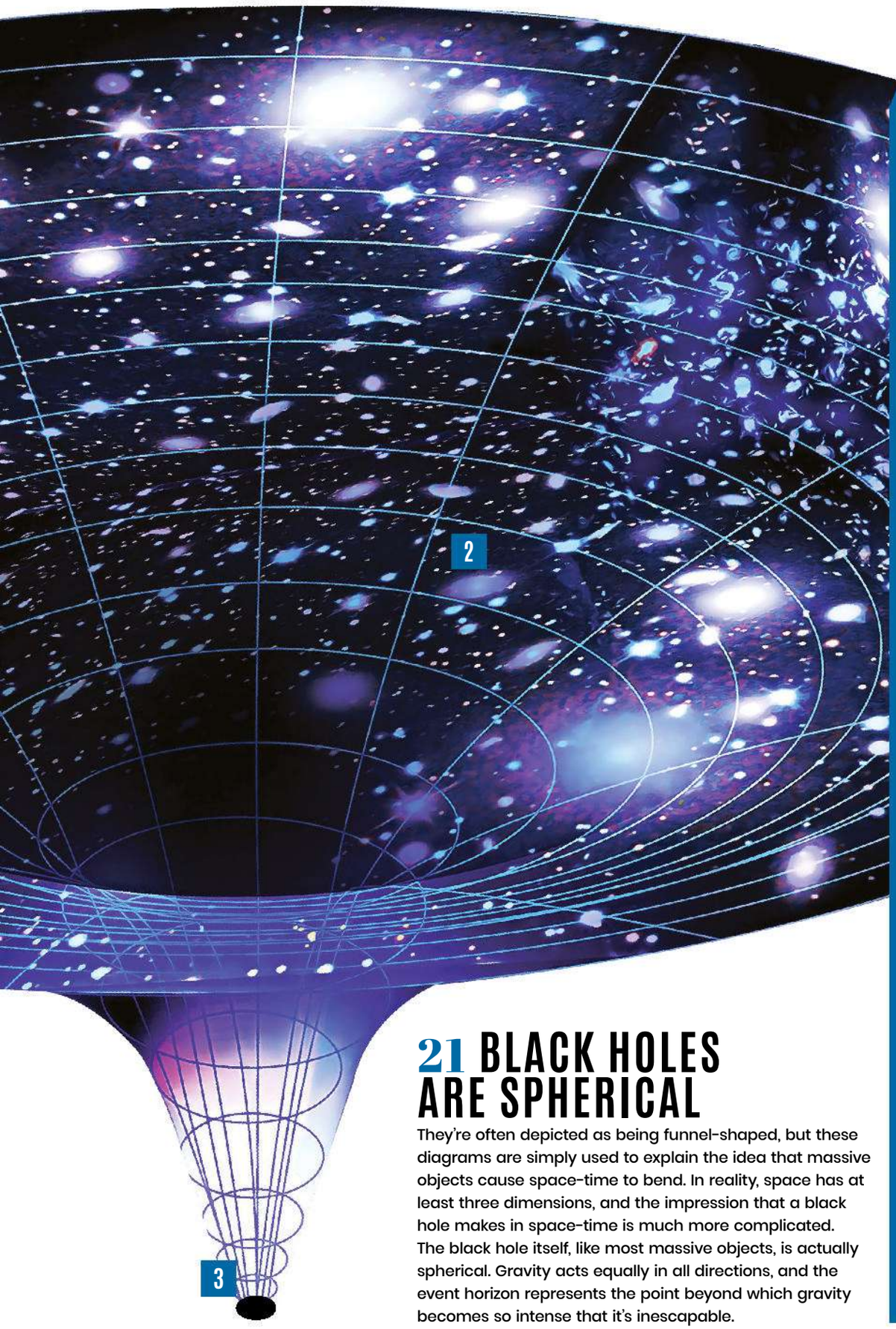
2 Infinite curve
The singularity is infinitely dense, creating an infinite curve in the fabric of space-time.

3 Focal point
Space and time are concentrated on a single spot at the singularity.



20 BLACK HOLES BEND SPACE-TIME

Einstein showed that the universe is made from a fabric known as space-time, and just like a piece of cloth, it can be bent, twisted and stretched. Massive objects, including planets and stars, make dips in the fabric of space-time, like bowling balls sitting on top of a trampoline. The more mass that's collected in one area, the more of an impression it makes in the fabric and the more energy is required to escape its gravitational field. One object in orbit around another can be thought of as being similar to a cyclist in a velodrome. The cyclist is trying to travel in a straight line. However, the curved floor forces them to move around in circles. If they pedal faster, they might be able to gather up enough speed to climb out of the top of the dome, and if they slow down they will start to drift back in towards the centre.



21 BLACK HOLES ARE SPHERICAL

They're often depicted as being funnel-shaped, but these diagrams are simply used to explain the idea that massive objects cause space-time to bend. In reality, space has at least three dimensions, and the impression that a black hole makes in space-time is much more complicated. The black hole itself, like most massive objects, is actually spherical. Gravity acts equally in all directions, and the event horizon represents the point beyond which gravity becomes so intense that it's inescapable.

We speak to Douglas Richstone of the University of Michigan about the origins of supermassive black holes

22 ALMOST EVERY GOOD-SIZED GALAXY HAS A SUPERMASSIVE BLACK HOLE

"For every galaxy that's reasonably good-sized and regular – that is, a galaxy with a disc and a bulge, and possibly spiral arms, or a so-called elliptical galaxy that looks round – there's a black hole. Moreover, the black hole's mass tracks the mass of the host galaxy and is about a thousandth of the galaxy's mass. These black holes range from 1 million to nearly 10 billion solar masses. However, for galaxies that are very small, irregular or possibly only have a disc and no round component, or bulge, the situation is much more complicated. Some of these galaxies appear to have black holes, while others don't."

23 QUIET SUPERMASSIVE BLACK HOLES USED TO BE QUASARS

"We don't know for certain how the biggest black holes form, but there is a clue. The amount of mass in galaxies at present tied up in black holes is almost exactly the amount of mass needed to power quasars [very bright objects thought to be black holes accreting matter] when the universe was about a fifth of its present age. It's reasonable to identify the black holes in galaxies now as the relics of quasars."

24 IT'S IMPOSSIBLE TO SEE THEM DIRECTLY

Black holes do not emit or reflect any electromagnetic radiation except Hawking radiation, but their gravitational effects are detectable.

25 SOME BLACK HOLES SPIN AT HALF THE SPEED OF LIGHT

By looking at the pattern of X-rays in the area surrounding a black hole, the speed at which it's spinning can be determined.

26 THERE ARE TWO DIFFERENT TYPES OF BLACK HOLE

Schwarzschild black holes are the simplest and are made up of just an event horizon and a singularity. Kerr black holes rotate and have a third component known as the ergosphere.

27 BLACK HOLES ARE NOISY

In 2003, NASA's Chandra X-ray Observatory revealed that a black hole in the Perseus Cluster makes a sound in the pitch of B flat.

28 WE'LL NEVER KNOW WHAT'S REALLY INSIDE A BLACK HOLE

Light cannot escape across the event horizon of a black hole, preventing us from ever seeing inside one. There's also no definitive answer about what really happens inside a black hole.

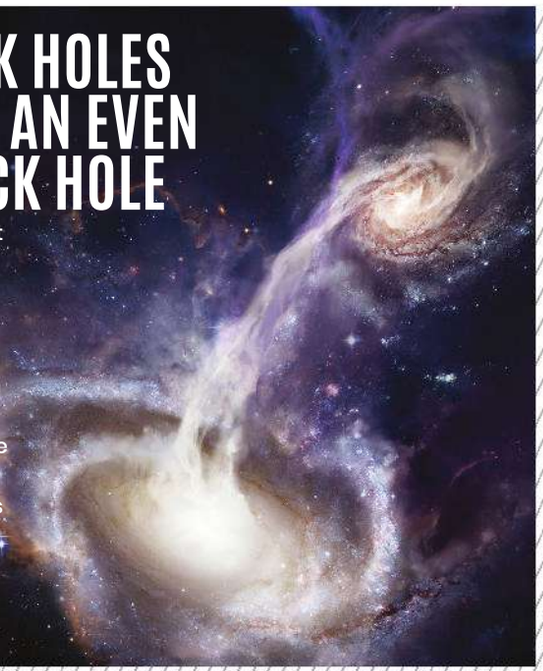
29 ONE DAY, BLACK HOLES WILL DOMINATE THE UNIVERSE

Black holes evaporate so slowly that they will exist long after the last of the stars fade and die, leading scientists to predict that one day they will be all that's left in the universe.

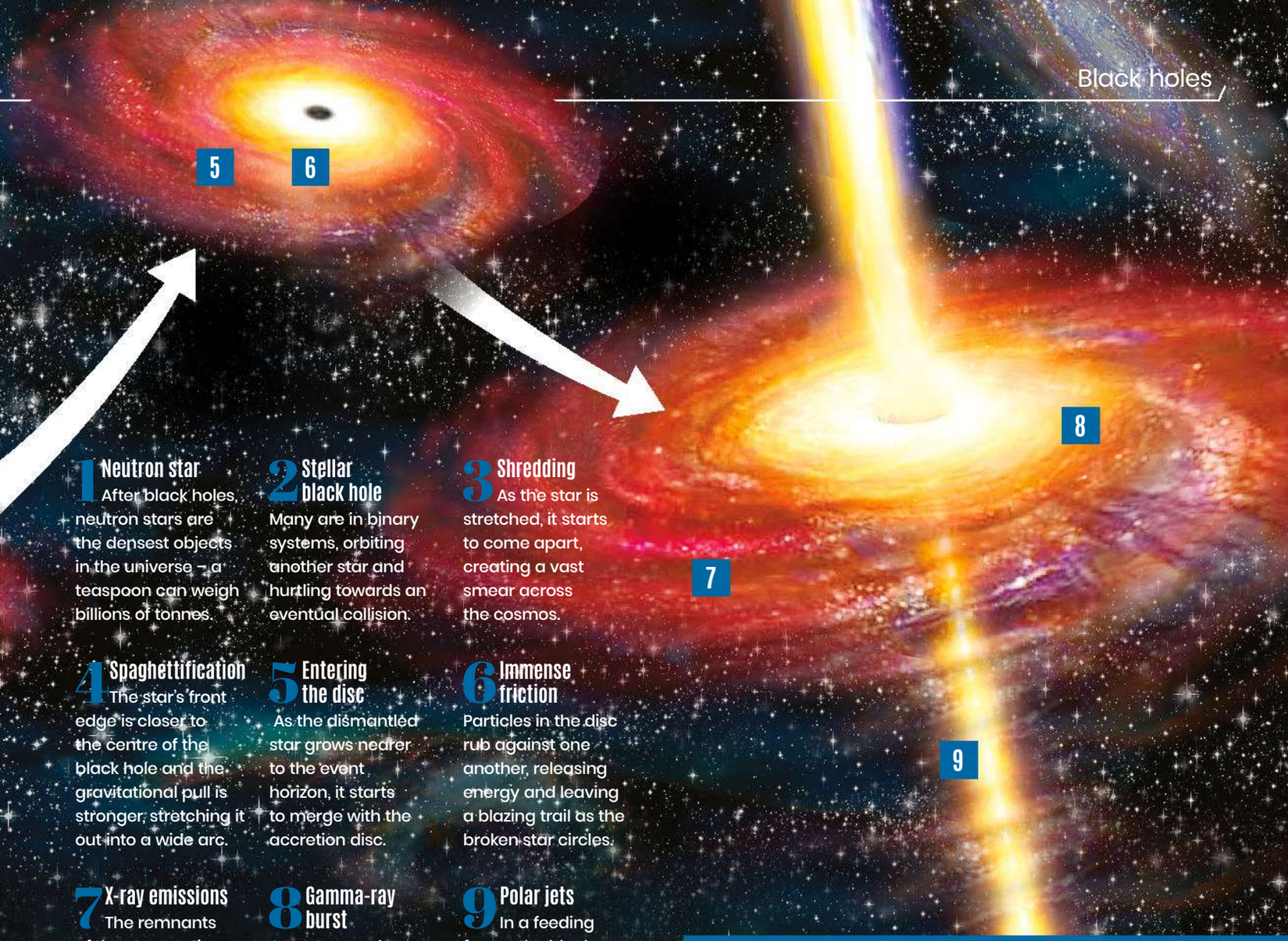
30 OBJECTS ARE STRETCHED LIKE SPAGHETTI AS THEY APPROACH A BLACK HOLE

As an object gets closer to a black hole, the gravitational pull rises sharply. The parts of the object that are closest to the black hole experience stronger attraction than those farther away, causing them to accelerate faster. This stretches the object as the front moves more quickly than the back, drawing it out into a long filament in a process known as spaghettification. The tidal forces around a black hole are strong enough that anything entering becomes stretched, from the largest stars to the smallest atoms. When the stretching force exceeds the elastic limit of the material, it starts to break apart, tearing into smaller and smaller pieces, each being stretched out until all that's left are elementary particles. Spaghettification takes place at different times depending on the size and type of black hole. For small stellar black holes, for example, it occurs before objects have crossed the event horizon. However, in supermassive black holes the tidal forces don't always become great enough until the object has crossed over the point of no return.

31 WHEN TWO BLACK HOLES COLLIDE, THEY FORM AN EVEN MORE MASSIVE BLACK HOLE



It's likely that the supermassive black holes at the centres of galaxies began to form early in the evolution of the universe. As matter condensed to form the first galaxies, it would have been much closer together, and small black holes would have been able to feast on dust and gas, becoming truly massive in a very short space of time. Several intermediate black holes are thought to have formed within clusters of stars before sinking towards the centres of galaxies under the influence of each other's gravitational pull, collapsing in on one another to form the supermassive giants that we see today.



1 Neutron star
After black holes, neutron stars are the densest objects in the universe – a teaspoon can weigh billions of tonnes.

2 Stellar black hole
Many are in binary systems, orbiting another star and hurtling towards an eventual collision.

3 Shredding
As the star is stretched, it starts to come apart, creating a vast smear across the cosmos.

4 Spaghettification
The star's front edge is closer to the centre of the black hole and the gravitational pull is stronger, stretching it out into a wide arc.

5 Entering the disc
As the dismantled star grows nearer to the event horizon, it starts to merge with the accretion disc.

6 Immense friction
Particles in the disc rub against one another, releasing energy and leaving a blazing trail as the broken star circles.

7 X-ray emissions
The remnants of the star continue to drop over the event horizon, releasing spikes of X-ray emissions.

8 Gamma-ray burst
As a star crashes into the black hole, most is swallowed in an instant, releasing gamma rays.

9 Polar jets
In a feeding frenzy, the black hole spits the excess back out, funnelling it away from the poles in bright jets.

32 THE LARGER THE BLACK HOLE, THE LESS DENSE IT IS

If the mass inside a black hole doubles, the volume of its event horizon increases eight times, making it more massive, but less dense.

The sponge is bigger and more massive. but less dense than the marble

33 EVEN SOME DWARF GALAXIES CAN HARBOUR SUPERMASSIVE BLACK HOLES

Anil Seth of the University of Utah discovered a supermassive black hole at the centre of a dwarf galaxy

What makes the black hole in the dwarf galaxy M60-UCD1 such an interesting find?
We think most big galaxies have supermassive black holes, but M60-UCD1 is much smaller and less massive than any other galaxy with one. Supermassive black holes play an important role in how galaxies form, and this provides a new environment for us to find these objects. Currently, we don't understand how supermassive black holes form because their formation happened early in the universe.

How did such a big black hole form in such a small galaxy?
M60-UCD1 got its name because it's just 22,000 light years from the giant elliptical galaxy Messier 60. We think that M60-UCD1 is in orbit around Messier 60 and was once a much larger galaxy. When it passed close to the centre of Messier 60, this once-bigger galaxy had its outer parts stripped away, leaving just the dense core of stars and the black hole behind.

34 BLACK HOLES WERE FIRST IMAGINED IN THE 18TH CENTURY

John Michell and Pierre-Simon Laplace were the first to wonder about the existence of black holes, imagining that beyond a certain point, the gravity of a massive object must become so great that nothing can get away. The trouble was that according to Newton's theory of gravitation, light wouldn't be affected by gravity because it has no mass. So no matter how massive an object became, light should be able to escape. It wasn't until Einstein's theory of general relativity that the physics of black holes really started to make sense.

"Beyond a certain point, the gravity of a massive object must become so great nothing can get away"

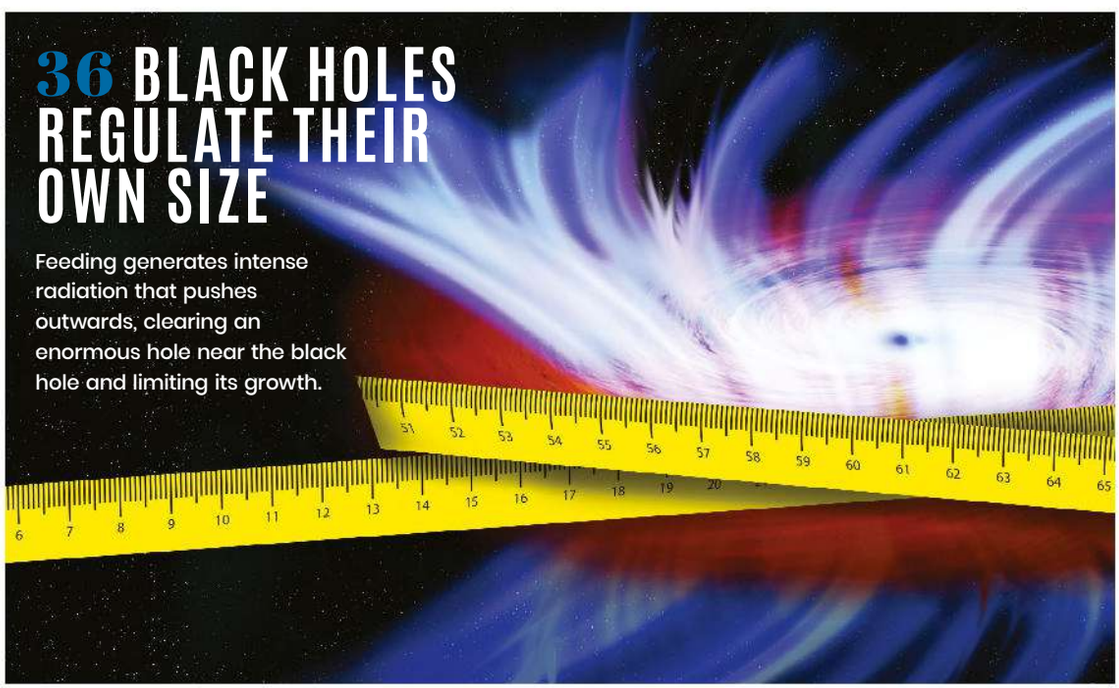
1 Hawking radiation
The strange physics around the perimeter of a black hole means that it's theoretically possible for matter to travel faster than the speed of light, escaping the void as Hawking radiation.

2 No singularity
Matter is temporarily trapped inside the black hole, condensed and unrecognisable, but never quite crushed to a single point.

3 Apparent horizon
Hawking theorised that instead of having an event horizon, black holes create such a disturbance in space-time that they can hold light temporarily around their edges.

35 BLACK HOLES MIGHT NOT EXIST

In 2014, Stephen Hawking put forward a controversial theory: they don't exist at all, at least not in the way we imagine them. The science of black holes is based on Einstein's theory of general relativity, but there are grey areas. One of the major problems is the event horizon. According to Einstein, it's the point at which matter crosses over into a black hole and gets destroyed as it's pulled towards the singularity. But according to quantum theory, the event horizon would actually be a 'firewall' of high-energy particles. The physics behind Einstein's theory contradict that of quantum theory. Hawking proposed the event horizon doesn't actually exist. Black holes are not bottomless pits from which nothing can return, and that instead they just temporarily hold and scramble matter before releasing it back into the universe as radiation.



36 BLACK HOLES REGULATE THEIR OWN SIZE

Feeding generates intense radiation that pushes outwards, clearing an enormous hole near the black hole and limiting its growth.

37 EVEN A ROCKET TRAVELLING AT THE SPEED OF LIGHT COULDN'T ESCAPE FROM A BLACK HOLE

As objects become more massive and more dense, it becomes increasingly hard to escape their gravitational pull. For a rocket to escape the gravity of Earth, it must travel at a speed of 11.2 kilometres (6.9 miles) per second. From the surface of the Sun that speed rises to 618 kilometres (1,005 miles) per second, and from a dense white dwarf star like Sirius B, the same rocket would need to travel at 5,200 kilometres (3,231 miles) per second in order to escape. Within the grip of a black hole, even a rocket travelling at the breakneck speed of light, or 299,792 kilometres (186,282 miles) per second, would be unable to free itself from the immense gravitational pull.

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38 SOME CAN BE TINY

The smallest theoretical mass for a black hole is around 22 micrograms, a value known as Planck mass.

39 THE CLOSEST KNOWN BLACK HOLE IS 1,560 LIGHT YEARS AWAY FROM EARTH

The closest black hole to Earth is Gaia BH1 in Ophiuchus. It has the mass of about 9.6 Suns.

40 BLACK HOLES HAVE NO HAIR

This famous statement made by scientist John Wheeler describes the simplicity of black holes. Typically, they can be described by just three quantities: their mass, angular momentum and electric charge.

41 THEY HALT LOCAL STAR FORMATION

The largest and most active supermassive black holes often occur in the quietest galaxies. The radiation released as they feed stops the gas around them condensing to form stars.

42 THE SUN COULD NEVER BECOME A BLACK HOLE

To become a black hole, a star must be so massive that it completely collapses under its own gravitational pull. The Sun is much too small, and instead it will end its life as a white dwarf.

43 BLACK HOLES COME IN DIFFERENT SIZES

Stellar-mass black holes can measure just a few kilometres in diameter, whereas supermassive black holes can be the size of our Solar System.

44 THERE'S A SUPERMASSIVE BLACK HOLE AT THE CENTRE OF THE MILKY WAY

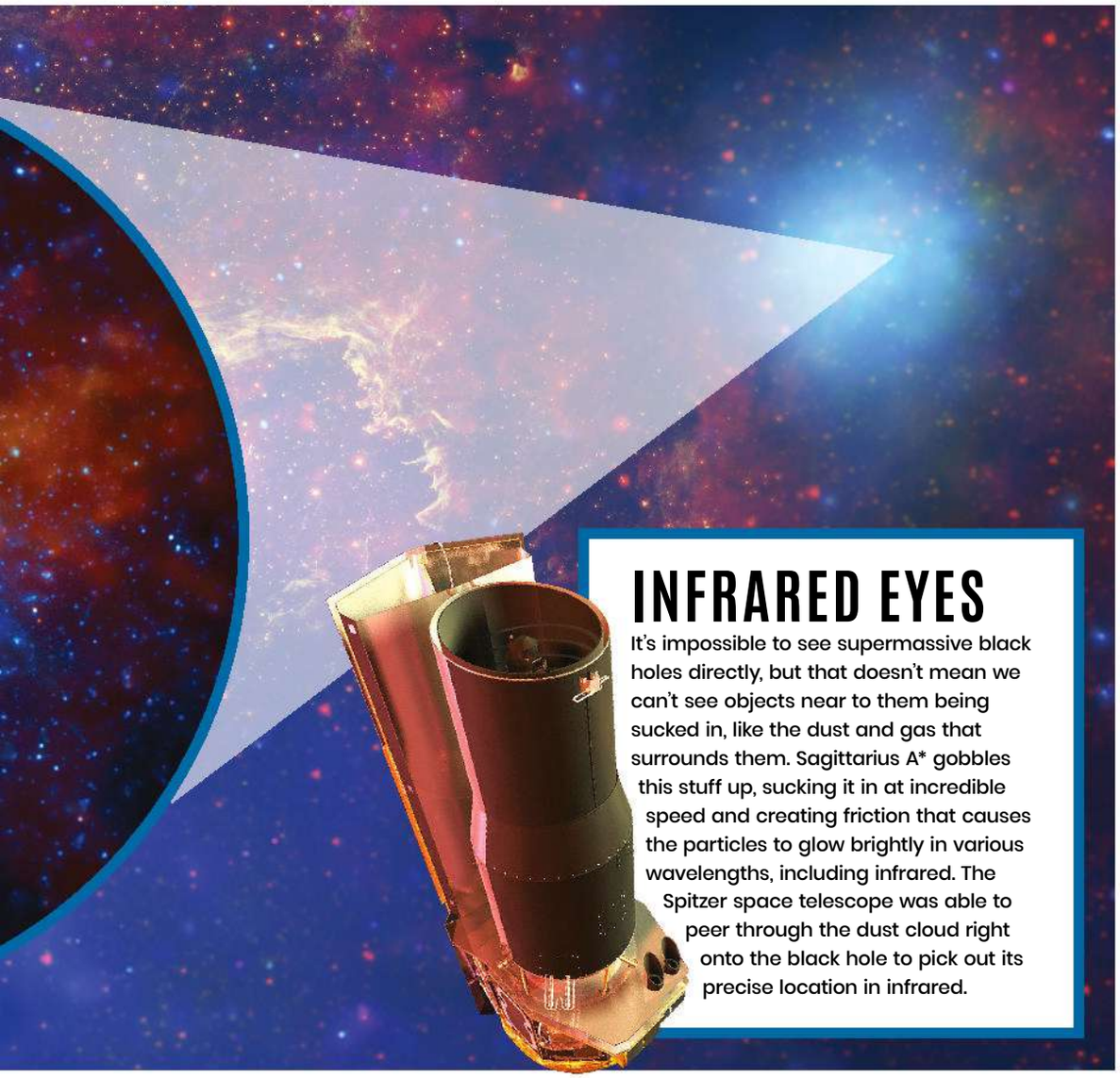
At the centre of the Milky Way, the stars move in strange circles. They hurtle towards a bright radio source, turn in a tight hairpin and then race away again. Tracing the lines of their orbits reveals that they all overlap at a single point, known as Sagittarius A*.

The region is shrouded in a thick cloud of dust and gas, making it difficult to see, but in order to account for these highly elliptical orbits, astronomers have calculated that Sagittarius A* must contain around 4 million solar masses, compressed into a volume with a radius of about 25 million kilometres (15.5 million miles).

Strange things happen around supermassive black hole Sagittarius A*

45 SOME BLACK HOLES POWER THE BRIGHTEST OBJECTS IN THE UNIVERSE

In the 1960s, astronomer Allan Sandage noticed a very bright object in the distant sky. It was as bright as a nearby star, but its vast distance meant it must be emitting hundreds of times as much energy as all of the stars in the Milky Way. Dubbed quasars, these objects are among the brightest in the universe and represent actively feeding supermassive black holes. Thousands have been identified, and each blazes brightly as matter tumbles onto its accretion disc, spewing X-rays and visible light into space.



INFRARED EYES

It's impossible to see supermassive black holes directly, but that doesn't mean we can't see objects near to them being sucked in, like the dust and gas that surrounds them. Sagittarius A* gobbles this stuff up, sucking it in at incredible speed and creating friction that causes the particles to glow brightly in various wavelengths, including infrared. The Spitzer space telescope was able to peer through the dust cloud right onto the black hole to pick out its precise location in infrared.

46 PARTICLE ACCELERATORS COULD CREATE MICROSCOPIC BLACK HOLES

When the Large Hadron Collider was switched on in 2008, there were concerns among scientists that the particles, travelling at close to the speed of light, could theoretically produce miniature black holes. So far, no such holes have been created, but it's definitely possible in theory. Even if a microscopic black hole was created, there would be little to worry about. The black hole would be so small that it would take billions of years for it to consume just one gram of matter.

47 SPACE AROUND A SPINNING BLACK HOLE IS WARPED

Spinning black holes distort space-time, wrapping it into a swirl known as the ergosphere. Within this area, space itself moves faster than the speed of light.

48 W49B IS THE YOUNGEST KNOWN IN THE MILKY WAY

A supernova remnant is all that remains of a star that exploded 1,000 years ago. There's no evidence of a neutron star at its core, leading astronomers to believe that it harbours a young black hole.

49 SPINNING BLACK HOLES HAVE A DOUGHNUT-SHAPED MAGNETIC FIELD FORMATION

As matter swirls around the accretion disc of a black hole, the magnetic fields line up, forming a doughnut-shaped ring with the event horizon nestled at the centre.

50 SMALLER GALAXIES CONTAIN MEDIUM-SIZED BLACK HOLES

It was originally thought that black holes only came in two sizes: stellar-mass black holes and supermassive black holes. However, researchers using data from NASA's Chandra X-Ray Observatory and Rossi X-Ray Timing Explorer (RXTE) were able to measure a medium-sized black hole in Messier 82 to be around 400 solar masses. Known as intermediate-mass black holes, these seeds of the most destructive objects in the universe contain between 100 and 10,000 times the mass of the Sun.

© NASA/ESA;

FOCUS ON

ASTRONOMERS SPOT THE MOST POWERFUL FLASH OF LIGHT EVER SEEN

The gamma-ray burst was also the nearest ever detected

Reported by Tereza Pultarova

Astronomers just detected what may be the most powerful flash of light ever seen. The gamma-ray burst, the most energetic type of electromagnetic explosion known to exist in the universe, was first spotted by telescopes on 9 October. Gamma-ray bursts, which were discovered accidentally by US military satellites in the 1960s, are likely produced when giant stars explode at the ends of their lives before collapsing into black holes, or when ultradense stellar remnants known as neutron stars collide. Within seconds, these explosions unleash as much energy as the Sun will emit during its entire 10-billion-year lifetime.

The flash was the strongest one ever observed, releasing 18 teraelectronvolts of energy. Scientists are still analysing the measurements, but if the findings are confirmed, the gamma-ray burst would be the first gamma-ray burst ever found to carry more than 10 teraelectronvolts of energy. At first the strength of the flash confused astronomers; they thought it must have been produced by a relatively close source. They also initially believed that the energy was coming in X-rays, rather than in gamma rays. Subsequent analyses of the signal confirmed that it was indeed a gamma-ray burst, coming from a source some 2.4 billion light years away. While not exactly nearby, the gamma-ray burst is still the closest ever seen.

Although this gamma-ray burst was within a safe distance from Earth, a much closer one would be catastrophic to our planet. Such an energetic flash within thousands of light years from Earth would strip the planet of its protective ozone layer and likely cause mass extinction. In fact, scientists think one of the biggest mass-extinction events in Earth's history - the Ordovician extinction, which occurred 450 million years ago – may have been triggered by such a blast.

The recently spotted gamma-ray burst, dubbed GRB 221009A, appeared 20 times closer to Earth than an average gamma-ray burst, but is still far enough away to cause more excitement than concern. "This event being so nearby but also very energetic means the radio, optical, X-ray and gamma-ray light it produces are all extremely bright and therefore easy to observe. We can therefore study this gamma-ray burst with lots of big and small telescopes around the world and collect very comprehensive datasets as it first brightens and then fades away," said Gemma Anderson, an astronomer at Curtin University in Australia who studies similar phenomena.

Gamma-ray bursts come in two varieties: short gamma-ray bursts are rarer and last no longer than two seconds. These bursts make up about 30 per cent of all such events and are believed to be caused by collisions of neutron stars. The other type, long gamma-

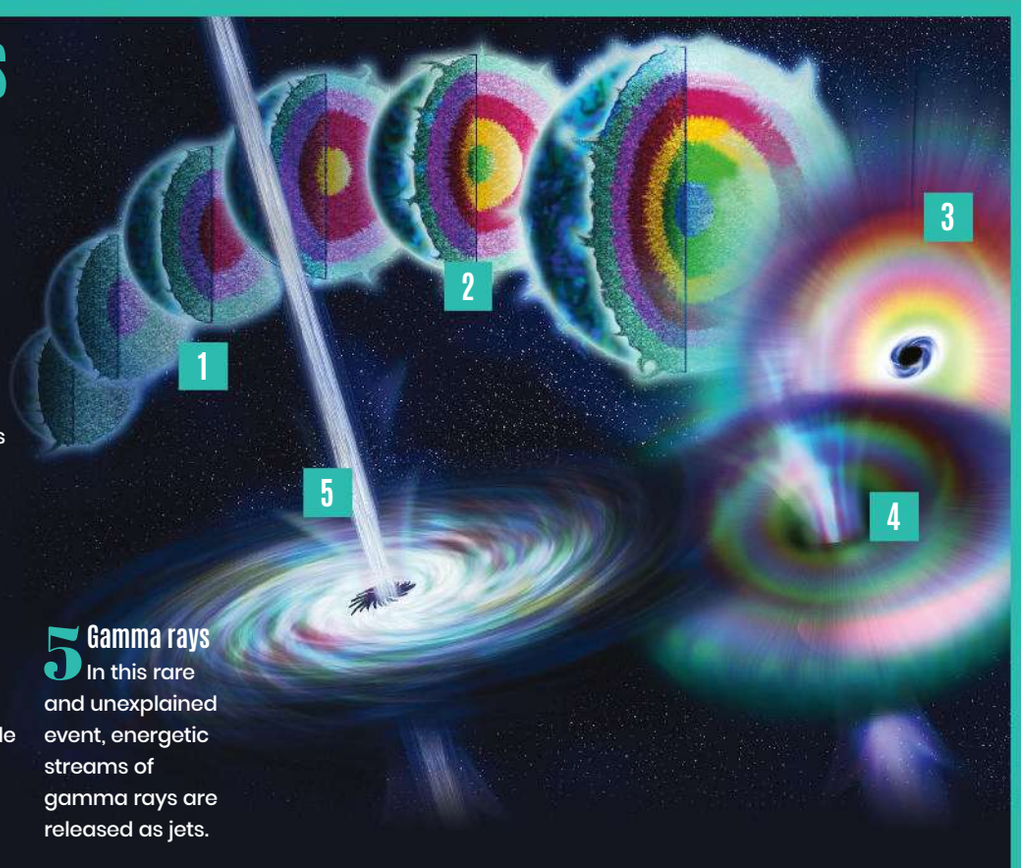
ray bursts, can last up to several minutes and are likely produced by hypernovae, stellar explosions that are 100 times brighter than supernovae, in which supermassive stars die after running out of the hydrogen fuel in their cores. Astronomers mostly see the afterglow of these stellar explosions, coming from electrons energised by the blast. GRB 221009A appears to be a long gamma-ray burst, but astronomers don't know yet what gave rise to it. "It's still too early to tell," Anderson said. "The light from an underlying supernova will take days to brighten. However, given this gamma-ray burst's long duration, it may be a very powerful type of supernova."

Telescopes all over the world and in Earth orbit are now pointing at the dusty galaxy from which the flash emerged. They will try to observe the light generated by the explosion in as many wavelengths as possible to get the most complete picture of its origin. "When you're dealing with cosmic explosions that blast out stellar remains at near the speed of light, leaving a black hole behind, you are watching physics occurring in the most extreme environments that are impossible to recreate on Earth," Anderson said. "We still don't fully understand this process. Such a nearby explosion means we can collect very high-quality data to study and understand how such explosions occur."

> "Given this gamma-ray burst's long duration, it may be a very powerful type of supernova"
>
> **Gemma Anderson**

GETTING TO GRIPS WITH GAMMA-RAY BURSTS

The history behind the biggest and brightest explosions in the universe



1 A star is born
A massive star begins its life cycle, from a protostar to a blue supergiant.

2 Bright future
Massive stars burn bright, but have short lives compared to the main sequence.

3 Burning out
The star rapidly burns through its fuel and explodes in a gigantic release of energy.

4 Black hole
A black hole is formed as nothing is capable of stopping the collapse of the star's mass.

5 Gamma rays
In this rare and unexplained event, energetic streams of gamma rays are released as jets.

©NASA

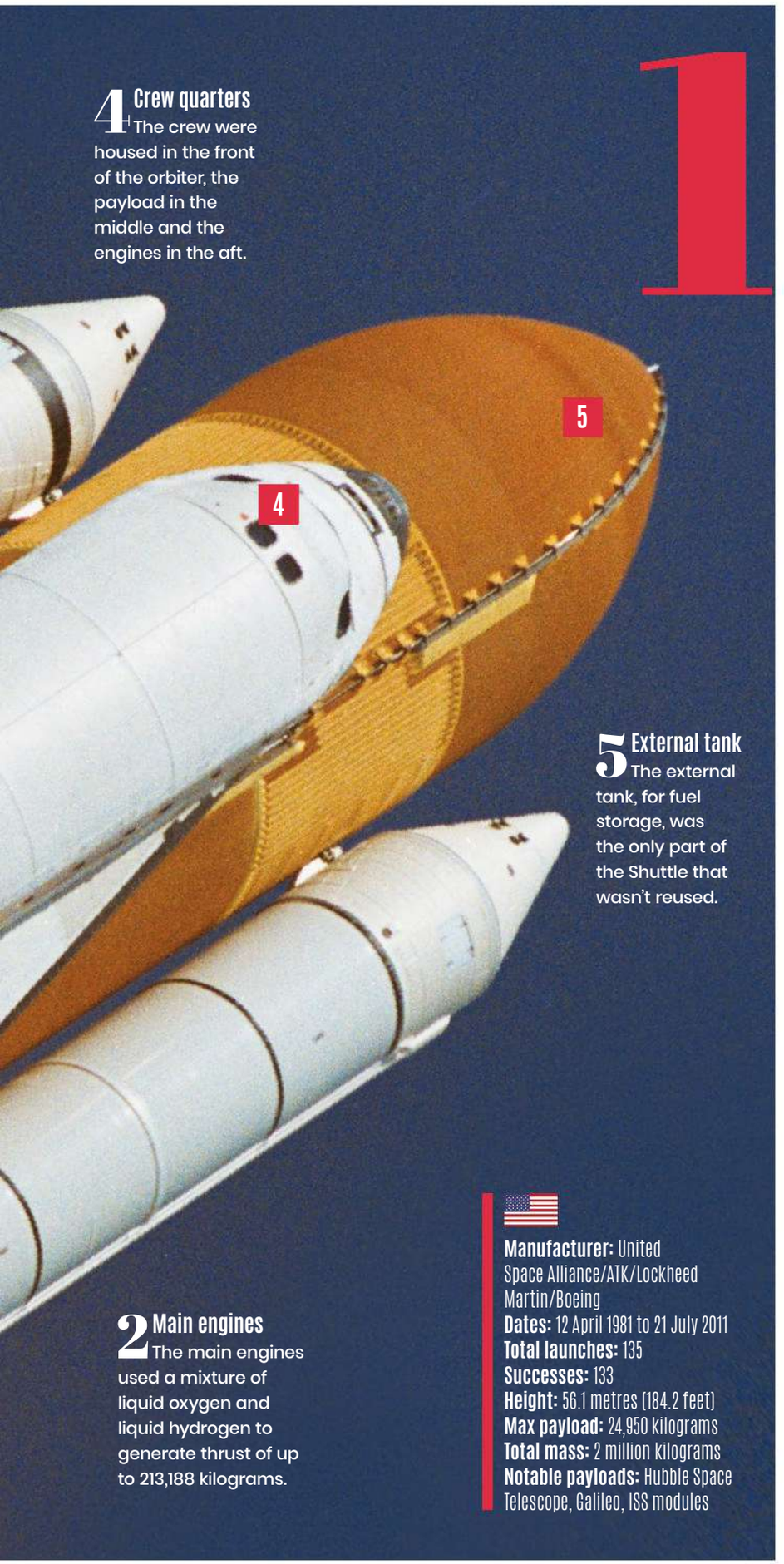
10 INCREDIBLE ROCKETS

Take a look at the biggest, best and most prolific launch vehicles to have reached space, from the early days of space exploration to the modern day

Written by Jonathan O'Callaghan

3 Orbiter
Each orbiter was 37 metres (121 feet) long, with a wingspan of 24 metres (78 feet) .

1 Solid rocket boosters
Two solid propellant boosters generated thrust of 1.2 million kilograms.



4 Crew quarters
The crew were housed in the front of the orbiter, the payload in the middle and the engines in the aft.

5 External tank
The external tank, for fuel storage, was the only part of the Shuttle that wasn't reused.

2 Main engines
The main engines used a mixture of liquid oxygen and liquid hydrogen to generate thrust of up to 213,188 kilograms.

Manufacturer: United Space Alliance/ATK/Lockheed Martin/Boeing
Dates: 12 April 1981 to 21 July 2011
Total launches: 135
Successes: 133
Height: 56.1 metres (184.2 feet)
Max payload: 24,950 kilograms
Total mass: 2 million kilograms
Notable payloads: Hubble Space Telescope, Galileo, ISS modules

1 SPACE SHUTTLE

The world's first reusable launch system

The Space Shuttle remains one of the most controversial spacecraft ever flown. While its awesome power and practical reusability were plain for all to see, a high cost and two devastating tragedies meant it was constantly under criticism. When the Shuttle program, officially called the Space Transportation System (STS), was stopped in 2011, it was therefore met with a mixture of sadness at seeing the vehicle retired, but also optimism for a new safer era of launchers.

Conceived in the 1960s and 1970s as a means to reach space regularly and reasonably, the Space Shuttle was in reality blighted by budget overruns and delays. When operational flights began in 1982 it was already proving expensive, but NASA made the most of the situation and cemented the Space Shuttle as its primary method of taking humans, cargo, satellites, probes and more into orbit.

This launcher was unique. Two solid rocket boosters were strapped to a central fuel tank, which worked in tandem with engines on the orbiter itself to get the vehicle to its lofty destination. While the main fuel tank was discarded in the upper atmosphere, the solid rocket boosters were recovered from the ocean to be used again – one of the first instances of rocket reusability. The orbiter itself was also reused. Six Space Shuttle orbiters were built in total, although one, Enterprise, was only used for testing and never entered space.

Technically, if you count the orbiter as a payload rather than a rocket, the STS is the closest challenger to the Saturn V for the most powerful retired rocket ever to have been launched. The maximum takeoff weight of a Shuttle orbiter – including the orbiter, fuel and a payload – was around 109,000 kilograms, with about 25,000 kilograms of that taken up by the useful payload. It was capable of taking cargo in its payload bay into low-Earth orbit (LEO), which could then be fired into orbit. It launched a huge number of well-known spacecraft, satellites, probes, telescopes and more. These include the Hubble Space Telescope, the Jupiter-orbiting Galileo spacecraft and many of the modules for the International Space Station.

2 DELTA IV

One of the most powerful rockets operating today

The Delta family of rockets has been used since the 1960s to take various government and private satellites into orbit. The Delta IV is the product of over half a century of upgrades. It employs many of the technologies used in previous Delta rockets, including the main tank and payload fairing, but also boasts advanced capabilities such as the use of liquid hydrogen fuel in its first stage, which makes it a relatively cheap but reliable option for getting satellites into orbit.

While most Delta IV rockets fall into the 'medium' category for launch vehicles, a larger and more powerful version known as the Delta IV Heavy has also come into use. First launched in 2004, the Heavy is capable of taking much bigger satellites – and more of them – into orbit. It has 13 fully successful launches under its belt, and one partial success. It is very similar to the Delta IV, but it has two additional boosters on the side that allow it to gain an increase in thrust.

Manufacturer: Boeing/United Launch Alliance
Dates: 20 November 2003 to present
Total launches: 41
Successes: 40
Height: 63 to 72 metres (206 to 235 feet)
Max payload: 23,000 kilograms
Total mass: 733,400 kilograms
Notable payloads: Eutelsat W5

The Delta IV Heavy is a more powerful iteration

Manufacturer: China Academy of Launch Vehicle Technology (CALT)
Dates: 19 November 1999 to present
Total launches: 18
Successes: 18
Height: 62 metres (203 feet)
Max payload: 8,400 kilograms
Total mass: 464,000 kilograms
Notable payloads: Shenzhou

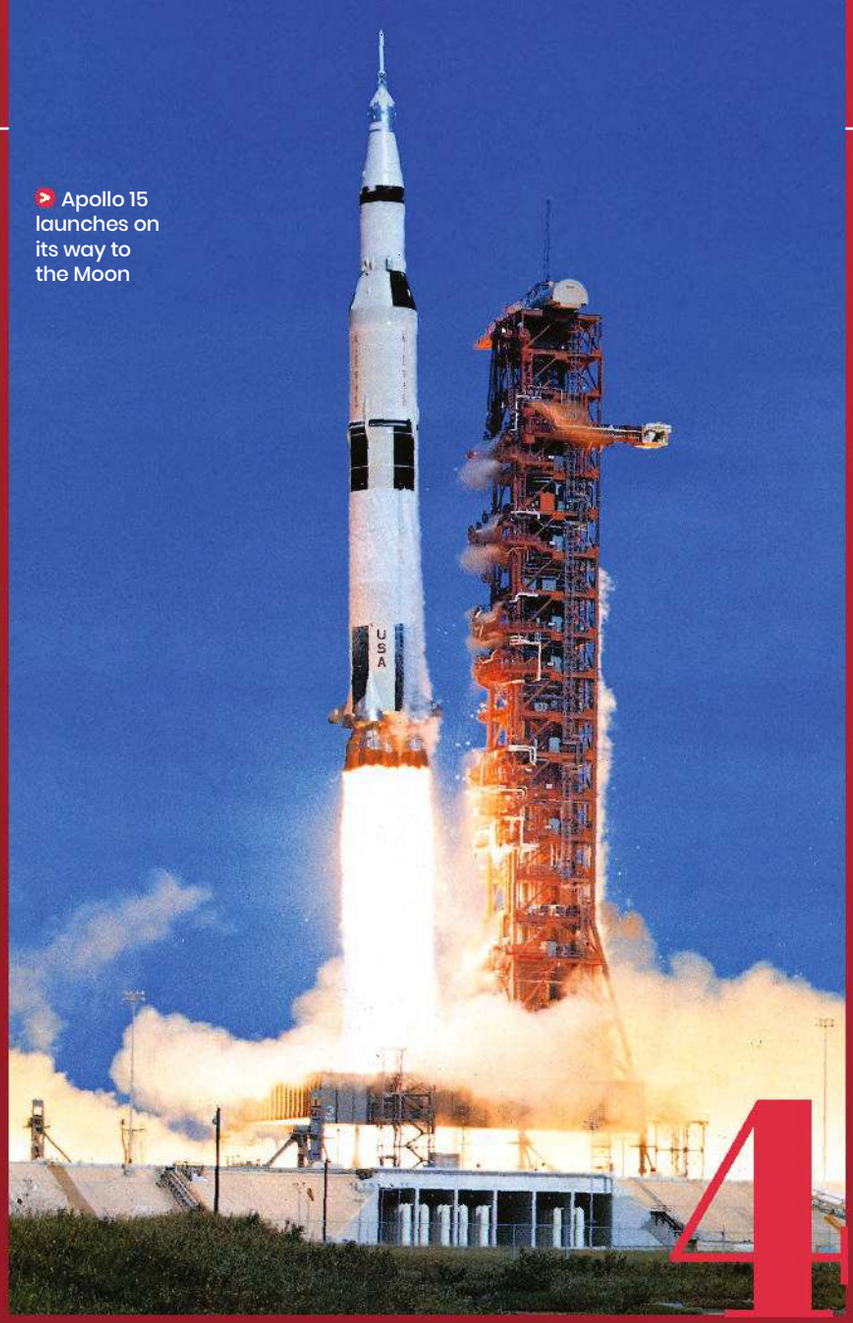
3 LONG MARCH 2F

This launched a new era of Chinese space exploration

The Long March family of rockets has been China's main means to reach the cosmos since its space program stepped up a gear in the 1990s. The first flight of the upgraded Long March 2F was an unmanned test of the Shenzhou spacecraft in 1999, with the first manned flight four years later. The Long March 2F has an enviable 100 per cent launch record, and in the past decade it was used to take up China's first orbital space station, Tiangong-1, as well as fly crew members there.

Around the central core of the rocket are four strap-on boosters that are discarded en route to orbit, while the core and final stage are dropped higher up. Unlike previous Chinese rockets, the Long March 2F was the first to be rolled out vertically to the launchpad, like some of its European and American counterparts. It will continue to be used for the foreseeable future, with its most recent launch on 4 August 2022.

The Long March 2F is a human-rated version of the previous Long March 2E



Apollo 15 launches on its way to the Moon

SATURN V

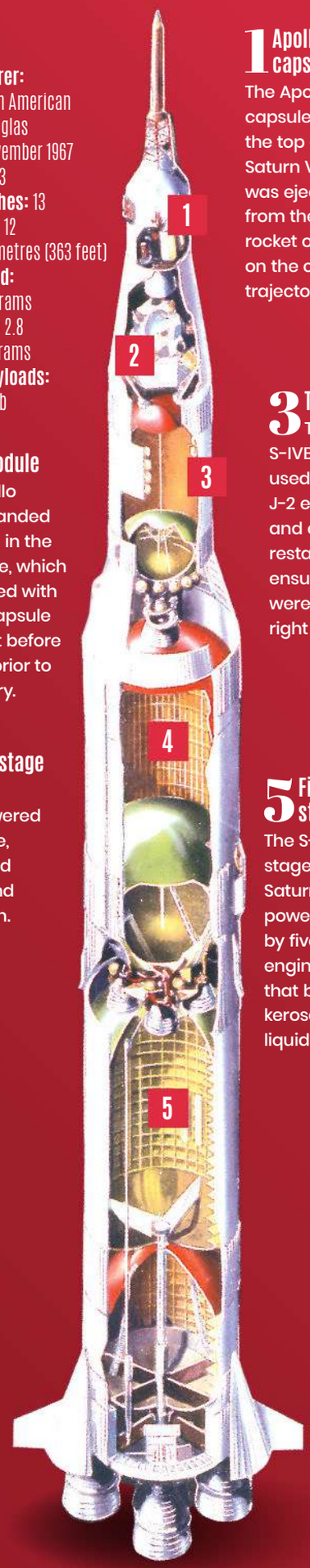
This famous rocket delivered humans to our lunar companion

If there's one rocket that elicits the fondest memories of a bygone age of space exploration, then the Saturn V has to be it. It's often bandied as the world's most powerful rocket – at least up until NASA's new Space Launch System (SLS) – but it's not until you stare at the figures that you realise just how powerful this vehicle really was. By comparison, the Delta IV Heavy has only about a quarter of the lifting capability of the Saturn V.

The original Saturn V made 12 launches, all of which were successful – except for one slight mishap during Apollo 6 – while a modified 13th was used to launch the Skylab space station in 1973. The Saturn V was massive, towering 111 metres (363 feet) high and weighing about 2.8 million kilograms – that's more than eight Atlas V rockets strapped together! It used a mixture of liquid hydrogen, liquid oxygen and kerosene as its fuel, and comprised three stages.

It was designed by rocket scientist Wernher von Braun, who is widely credited with advancing rocket technology like no one else in the 1940s, 1950s and 1960s. Its predecessors were the Jupiter series of rockets and later the Saturn I. The Saturn V was the first vehicle to take humans beyond Earth orbit, during the Apollo missions. In total it took 21 people to the Moon – three of them twice – and without it our lunar exploration missions simply wouldn't have been possible.

Manufacturer: Boeing/North American Aviation/Douglas
Dates: 9 November 1967 to 14 May 1973
Total launches: 13
Successes: 12
Height: 111 metres (363 feet)
Max payload: 120,000 kilograms
Total mass: 2.8 million kilograms
Notable payloads: Apollo, Skylab



1 Apollo capsule
The Apollo capsule sat on the top of the Saturn V and was ejected from the main rocket once on the correct trajectory.

2 Lunar Module
The Apollo astronauts landed on the Moon in the Lunar Module, which then redocked with the Apollo capsule in lunar orbit before separation prior to Earth re-entry.

3 Third stage
The final S-IVB stage used a single J-2 engine and could be restarted to ensure they were on the right course.

4 Second stage
Five J-2 engines powered the S-II stage, burning liquid hydrogen and liquid oxygen.

5 First stage
The S-IC stage of the Saturn V was powered by five F-1 engines that burned kerosene and liquid oxygen.

5

SOYUZ-FG

Once the industry's most frequently used rocket

Manufacturer: TsSKB-Progress
Dates: 20 May 2001 to 25 September 2019
Total launches: 70
Successes: 69
Height: 49.5 metres (162.4 feet)
Max payload: 7,100 kilograms
Total mass: 305,000 kilograms
Notable payloads: Soyuz, Progress

When it comes to old hands, nothing compares to the Soyuz rocket family. Indeed, they are the most frequently used series of rockets, with over 1,900 launches notched up and counting. Initially it launched the Soviet Union into the Space Race, but then it was used to transport astronauts from all over the world to the International Space Station. It flew for the first time on 20 May 2001 and continued to perform admirably. Indeed, of its 70 launches, only one has ever failed.

Unlike many other rockets, all three stages of the Soyuz-FG used the same type of fuel – in this case kerosene and liquid oxygen. It had four strap-on boosters around a central core stage, which were jettisoned once their tanks were empty, to lift the vehicle into space. As with all human-rated rockets, it had a launch abort system to carry the crew to safety in the event of a launchpad emergency, though this was never required. Its replacement, the Soyuz-2, has already performed over 150 launches, with many more planned.

Soyuz-FG rockets were used for manned launches to the ISS

6

PROTON-M

Russia's heavy-lift specialist rocket

In operation from 1965 until the present day, the Proton series of rockets remains one of the most successful heavy launch vehicles ever built. These unmanned rockets were designed for commercial and government launches, and 380 out of their 428 launches have been successful. The Proton-M is the latest member of the family, coming into service in April 2001 and still in use today. It's mainly used for commercial launches marketed by International Launch Services (ILS).

In its over 21 years of service the Proton-M has racked up 102 successful launches and two partial successes out of a total 113. The rocket has three stages – all of which are discarded after takeoff – while an optional fourth stage can be added to boost the orbit of a satellite – for example if it needs to reach geostationary orbit. The Proton, like the Soyuz, has been the cornerstone of Russia's space endeavours for many decades, and will continue to be so for years to come.

The latest Proton-M flight was on 12 October 2022

Manufacturer: Khrunichev
Dates: 7 April 2001 to present
Total launches: 113
Successes: 102
Height: 53 metres (174 feet)
Max payload: 22,000 kilograms
Total mass: 712,800 kilograms
Notable payloads: Intelsat, Eutelsat

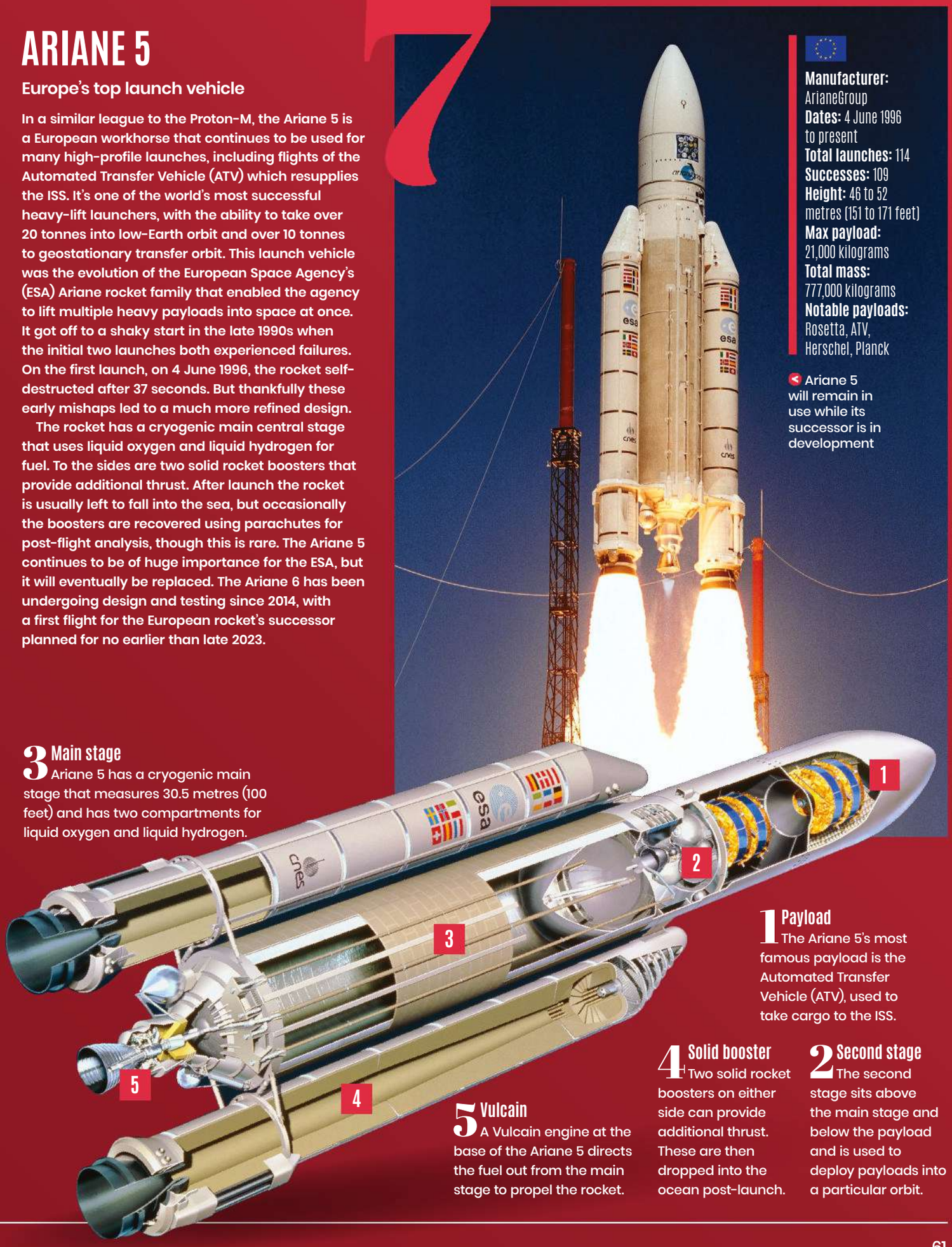
7

ARIANE 5

Europe's top launch vehicle

In a similar league to the Proton-M, the Ariane 5 is a European workhorse that continues to be used for many high-profile launches, including flights of the Automated Transfer Vehicle (ATV) which resupplies the ISS. It's one of the world's most successful heavy-lift launchers, with the ability to take over 20 tonnes into low-Earth orbit and over 10 tonnes to geostationary transfer orbit. This launch vehicle was the evolution of the European Space Agency's (ESA) Ariane rocket family that enabled the agency to lift multiple heavy payloads into space at once. It got off to a shaky start in the late 1990s when the initial two launches both experienced failures. On the first launch, on 4 June 1996, the rocket self-destructed after 37 seconds. But thankfully these early mishaps led to a much more refined design.

The rocket has a cryogenic main central stage that uses liquid oxygen and liquid hydrogen for fuel. To the sides are two solid rocket boosters that provide additional thrust. After launch the rocket is usually left to fall into the sea, but occasionally the boosters are recovered using parachutes for post-flight analysis, though this is rare. The Ariane 5 continues to be of huge importance for the ESA, but it will eventually be replaced. The Ariane 6 has been undergoing design and testing since 2014, with a first flight for the European rocket's successor planned for no earlier than late 2023.



Manufacturer: ArianeGroup
Dates: 4 June 1996 to present
Total launches: 114
Successes: 109
Height: 46 to 52 metres (151 to 171 feet)
Max payload: 21,000 kilograms
Total mass: 777,000 kilograms
Notable payloads: Rosetta, ATV, Herschel, Planck

Ariane 5 will remain in use while its successor is in development

3 Main stage
Ariane 5 has a cryogenic main stage that measures 30.5 metres (100 feet) and has two compartments for liquid oxygen and liquid hydrogen.

1 Payload
The Ariane 5's most famous payload is the Automated Transfer Vehicle (ATV), used to take cargo to the ISS.

4 Solid booster
Two solid rocket boosters on either side can provide additional thrust. These are then dropped into the ocean post-launch.

2 Second stage
The second stage sits above the main stage and below the payload and is used to deploy payloads into a particular orbit.

5 Vulcain
A Vulcain engine at the base of the Ariane 5 directs the fuel out from the main stage to propel the rocket.

8 ATLAS V

America's first choice for deep-space missions

As the latest iteration in the Atlas family of rockets – the first of which launched the Mercury astronauts back in the early 1960s – the Atlas V has been a massive success over the decades. Originally operated by Lockheed Martin, and now by United Launch Alliance, the Atlas V boasts an impressive 100 per cent success record from its 96 launches, although one did experience a minor fault. Since its first launch on 21 August 2002 it has transported various notable payloads into space, including the New Horizons probe and the Curiosity rover to Mars, and it continues to be called upon for high-profile launches today.

The Atlas V comes in a variety of configurations that can be altered depending on what type of launch is needed. The rocket can support between one and five solid rocket boosters, with a higher number enabling a heavier payload to be taken into low-Earth orbit (LEO) or beyond. Interestingly, future iterations of the Atlas V may also allow an additional central Centaur stage to be attached to the rocket, which would mean even bigger payloads could be taken into space, such as a manned crew capsule.

Manufacturer: United Launch Alliance
Dates: 21 August 2002 to present
Total launches: 96
Successes: 95
Height: 58.3 metres (191.2 feet)
Max payload: 29,400 kilograms
Total mass: 334,500 kilograms
Notable payloads: New Horizons, Juno, Curiosity

The Atlas V has never had a launch failure in over 20 years of service

9 TITAN IV

The workhorse of the American space program

The Titan family of rockets is perhaps best known for launching the American Project Gemini manned flights during the Space Race in the 1960s. Titan quickly established itself as the workhorse of the US space program for decades, launching numerous probes into the outer Solar System, including the famous Voyager spacecraft, both of which have now passed the boundary of interstellar space.

The later Titan IV became one of the primary rockets used by the US Air Force. Its high level of configurability made it ideal for a wide variety of launches into many different orbits. Its most notable launch was the Cassini-Huygens spacecraft in 1997, which remained in orbit around Saturn until 2017. Barring a few early failures, the Titan IV had a successful lifetime, completing 35 launches, mostly on behalf of the US Air Force. Ultimately, however, it was rendered obsolete with the arrival of the Atlas V and Delta IV rockets, and as a result was eventually retired in 2005.

Manufacturer: Lockheed Martin
Dates: 14 June 1989 to 19 October 2005
Total launches: 39
Successes: 35
Height: 61.9 metres (203 feet)
Max payload: 21,680 kilograms
Total mass: 943,050 kilograms
Notable payloads: Cassini-Huygens

Most of Titan IV's launches were for the US Air Force

10

FALCON 9

The first launcher to be backed by a private enterprise

Private spaceflight company SpaceX had an aim to shake up the launch vehicle market, designing and developing a new breed of low-cost reusable rocket that brought down the cost of taking payloads into orbit significantly. The Falcon 9 was the follow-up to the moderately successful Falcon 1 rocket. The latter was SpaceX's first foray into launch vehicles, achieving its first successful launch in 2008 after three failures and making SpaceX the first company to send a privately funded rocket to orbit.

While the Falcon 1 was more of a demonstration of SpaceX's capabilities, the Falcon 9 quickly became a big player in the launch vehicle market. It has 183 launches under its belt in three different iterations, with the latest dubbed the Full Thrust (FT). Its most notable payload is the Dragon spacecraft, the first private spacecraft to dock with the ISS, as well as the Crew Dragon. The Falcon 9 is under contract with NASA to resupply the ISS, with many more launches of the Dragon spacecraft scheduled for the coming years. The Falcon 9 will also be used to take other payloads – both government and commercial – into orbit.

The Falcon 9 is a two-stage-to-orbit vehicle that uses liquid oxygen and rocket-grade kerosene as fuel. Its upper stage is powered by SpaceX's own Merlin engine, which is derived from NASA's successful Apollo missions in the 1960s and 1970s. Falcon 9 is still relatively young in terms of launch vehicles, but its importance can't be underestimated. With every successful flight, SpaceX moves closer to its goal of bringing down the cost of reaching space.

> The Falcon 9 launches from Cape Canaveral, Florida

< SpaceX's Dragon spacecraft travel to the ISS using Falcon 9 rockets

Manufacturer: SpaceX
Dates: 4 June 2010 to present
Total launches: 183
Successes: 181
Height: 54.9 to 70 metres (180 to 230 feet)
Max payload: 22,680 kilograms
Total mass: 548,847 kilograms
Notable payloads: Dragon

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FOCUS ON

A BLACK HOLE IS BURPING OUT A STAR IT DEVOURED YEARS AGO

The aftermath of the star being spaghettified is like nothing astronomers have ever seen

Reported by Robert Lea

Three years after a black hole shredded and devoured a small star, the cosmic titan is lighting up the night sky with violent emissions as it burps out material from its messy stellar meal. In October 2018 the black hole, located in a galaxy 665 million light years from Earth, was observed tearing up a star that had wandered too close. The event itself wasn't surprising to astronomers, who often observe these violent encounters between stars and greedy black holes. These so-called tidal disruption events (TDEs) happen when objects such as stars approach black holes and the massive gravitational influence they encounter generates tidal forces that stretch the star in one direction while squashing it in the other direction, thus 'spaghettifying', or stretching out, the stellar body.

As this spaghettified material falls onto the black hole, it heats up and generates a flash of light that astronomers can spot from millions of light years away. Occasionally, the black hole spits some of this stellar material back out into space. In other words, black holes are messy eaters. However, there's something unusual about this TDE, designated AT2018hyz – despite not having feasted on anything since this small star, which had about one-tenth the mass of the Sun, the black hole is now spewing the material from its last meal.

"This caught us completely by surprise – no one has ever seen anything like this before," said Yvette Cendes, an astronomer at the Harvard-Smithsonian Center for Astrophysics, who led the research. "It's as if this black hole has started abruptly burping out a bunch of material from the star it ate years ago." Cendes and her team determined that this material is being ejected from the black hole at around 480 million kilometres per hour (300 million miles per hour), about half the speed of light. For comparison, TDEs usually spit out this material at about ten per cent the speed of light. Why it took so long for this black hole to burp out its last meal is also a mystery. "This is the first time that we have witnessed such a long delay between the feeding and the outflow," said Edo Berger, an astronomy professor at Harvard University.

The astronomers spotted this event as they were searching for signs of TDEs that have occurred over the past few years. Data they collected in radio waves with the Very Large Array (VLA) in New Mexico showed that this black hole had mysteriously burst back to life in June 2021. This finding encouraged them to investigate AT2018hyz further. "We applied for Director's Discretionary Time on multiple telescopes, which is when you find something so unexpected you can't wait for the normal cycle of telescope proposals to

observe it," Cendes said. "All the applications were immediately accepted."

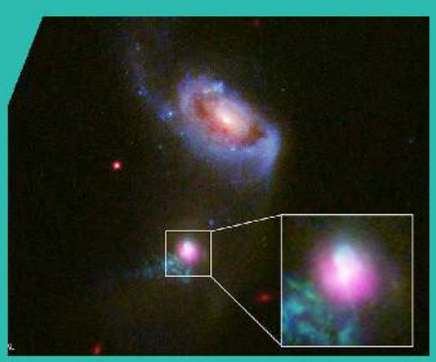
The team studied the event in multiple wavelengths of light and with a range of telescopes, including the VLA, the MeerKAT radio telescope in South Africa and the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile, finding that the most striking observations of AT2018hyz were in radio frequencies. "We have been studying TDEs with radio telescopes for more than a decade, and we sometimes find they shine in radio waves as they spew out material while the star is first being consumed by the black hole," Berger said. "But in AT2018hyz there was radio silence for the first three years, and now it's dramatically lit up to become one of the most radio-luminous TDEs ever observed."

Study coauthor Sebastian Gomez, a postdoctoral fellow at the Space Telescope Science Institute in Baltimore, Maryland, studied AT2018hyz in 2018 with visible-light telescopes like the 1.2-metre (3.9-foot) telescope at the Fred Lawrence Whipple Observatory in Arizona. At that time, he had considered this TDE unremarkable. "We monitored AT2018hyz in visible light for several months until it faded away, and then set it out of our minds," Gomez said. Now the team will investigate whether the delay between feeding and emitting is unique to AT2018hyz or if it's a more common event that astronomers have missed. "The next step is to explore whether this actually happens more regularly and we have simply not been looking at TDEs late enough in their evolution," Berger said.

An illustration of a black hole spewing material from a star it devoured

A SUPERMASSIVE BURP

In 2018, astronomers revealed something rather unusual: a few years earlier they'd seen a supermassive black hole appear to 'burp' twice. Called SDSS J1354+1327, the galaxy containing the black hole is located about 800 million light years from Earth. On two occasions, 100,000 years apart, it expelled bursts of high-energy particles in the form of bright light. The astronomers didn't see the burps in action, but they did see two emissions on either side of the galaxy that appeared to be the remnants of them. They're thought to have happened about a million years ago. But why? The answer comes from a nearby companion galaxy. It looks like the two galaxies collided in the past, and they're still linked by streams of stars and gas. The black hole ate material, namely extremely hot gas, from the companion galaxy on two separate occasions, and in the process flared up and released matter. Many other black holes have been known to belch too.



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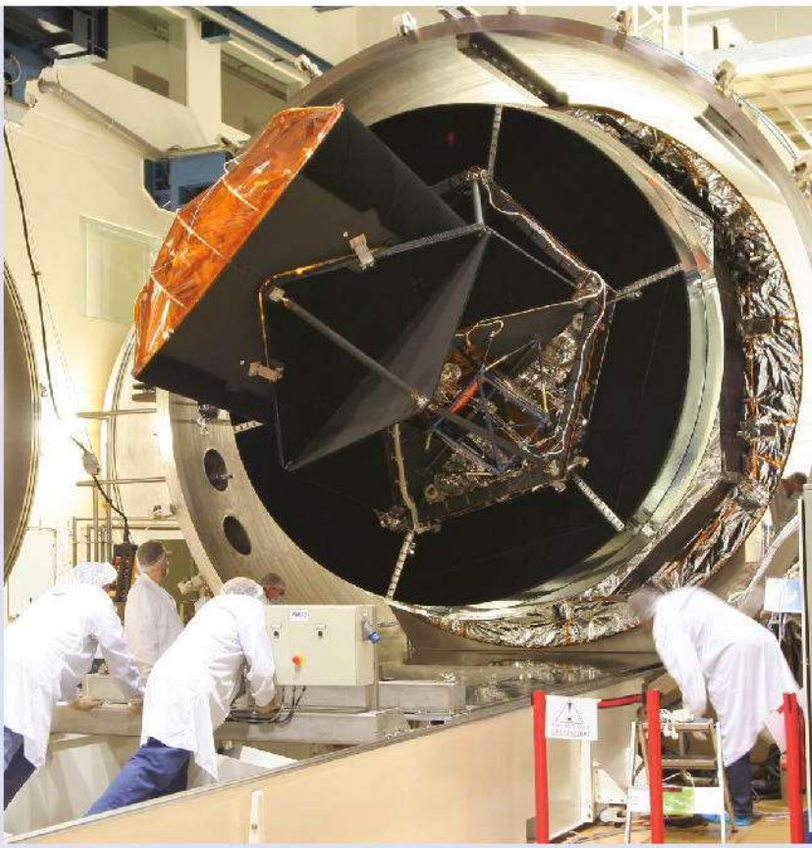
WHAT HAPPENED BEFORE THE BIG BANG?

Could there have been a time before the birth of the universe?

Reported by Kulvinder Singh Chadha



Planck mapped the cosmic microwave background, relic radiation from the universe's creation

Could there have been a time before the Big Bang? In other words, could the universe have existed before it even began? May there have even been previous universes? Such ideas, once the preserve of high-concept science fiction and philosophical debates, are gaining a new scientific credibility in the 21st century. Some cosmologists are wondering if the Big Bang was merely an intermediate phase and not the true start of the universe at all. Theories such as the ekpyrotic universe, 'Big Bounce' models and cyclic cosmology have been around for a while, but data from sensitive space probes could put some of these on a firmer footing. But what exactly was the Big Bang, and why are some scientists now changing their minds about it?

The widely accepted standard cosmological model states that the universe came into being from a superhot, superdense state that was no bigger than an atom and made of pure energy. Not much about that is contentious, but things get precarious with what happens next. This object, known as the 'initial singularity', is thought to have been timeless and dimensionless; there was nothing 'outside' of the singularity to speak of. Then, 13.82 billion years ago – a figure obtained from NASA's Wilkinson Microwave Anisotropy Probe (WMAP) and European Space Agency's (ESA) Planck satellite – this microscopic singularity expanded rapidly to the size of a football. This was the 'Big Bang'. But it wasn't an explosion. The universe never exploded into being. Rather, this initial expansion from microscopic quantum fluctuations birthed space and time and seeded the large-scale structure of the universe. This 'Big Bang' model has served cosmology well for over 80 years, but there have always been unanswered questions.

Despite the Big Bang theory being the cornerstone of cosmology, a theory called cosmic inflation was proposed in the 1980s to address some of the problems with the original model, such as the horizon problem – how has the universe 'homogenised' on the largest scales when it hasn't existed for long enough to do so, given its enormous size? Cosmic inflation theory proposes an extremely rapid initial expansion rate of 10^{-32} seconds. The universe would then have continued expanding in line with the Big Bang theory.

As the universe expanded, it also cooled, which resulted in energy condensing into matter known as subatomic particles. This transformation of energy into matter, predicted by Einstein's theory of special relativity, is described by the most famous equation in science: $E=mc^2$. The universe, still seething and hot, was then a dense morass of quarks and electrons, with photons of electromagnetism, including those of visible light, trapped within it. After 380,000 years this still-expanding universe cooled enough for the first chemical elements, hydrogen, helium and lithium, to form. The quarks turned into the protons and neutrons of atomic nuclei, capturing free-travelling electrons in the process to make atoms. This was the point at which all of the trapped photons of the electromagnetic spectrum could travel unhindered. In other words, the universe became transparent. But it was still dark; it took another 400 million years for the first stars and galaxies to form.

Dense hydrogen and helium gas clumps collapsed under gravity, possibly collecting within a large 'dark matter halo', until atomic nuclei in their cores began fusing together, known as thermonuclear fusion, which released large amounts of energy as the first stars came alight. Galaxies formed within these haloes.

It's strange to think that our universe could have existed before any of these events, but the Big Bang wasn't always accepted. Eminent British astronomer Sir Fred Hoyle, who coined the term 'Big Bang' in a BBC radio interview in 1949, actually hated the idea. So why

WHAT IS A SINGULARITY?

Singularities are regions of space and time with extreme gravity, where not even light can escape, and infinite density. They are thought to exist inside black holes, and our universe is thought to have started from one, too. Although predicted by the general theory of relativity, neither that or quantum mechanics can explain singularities. They still remain truly mysterious to science.

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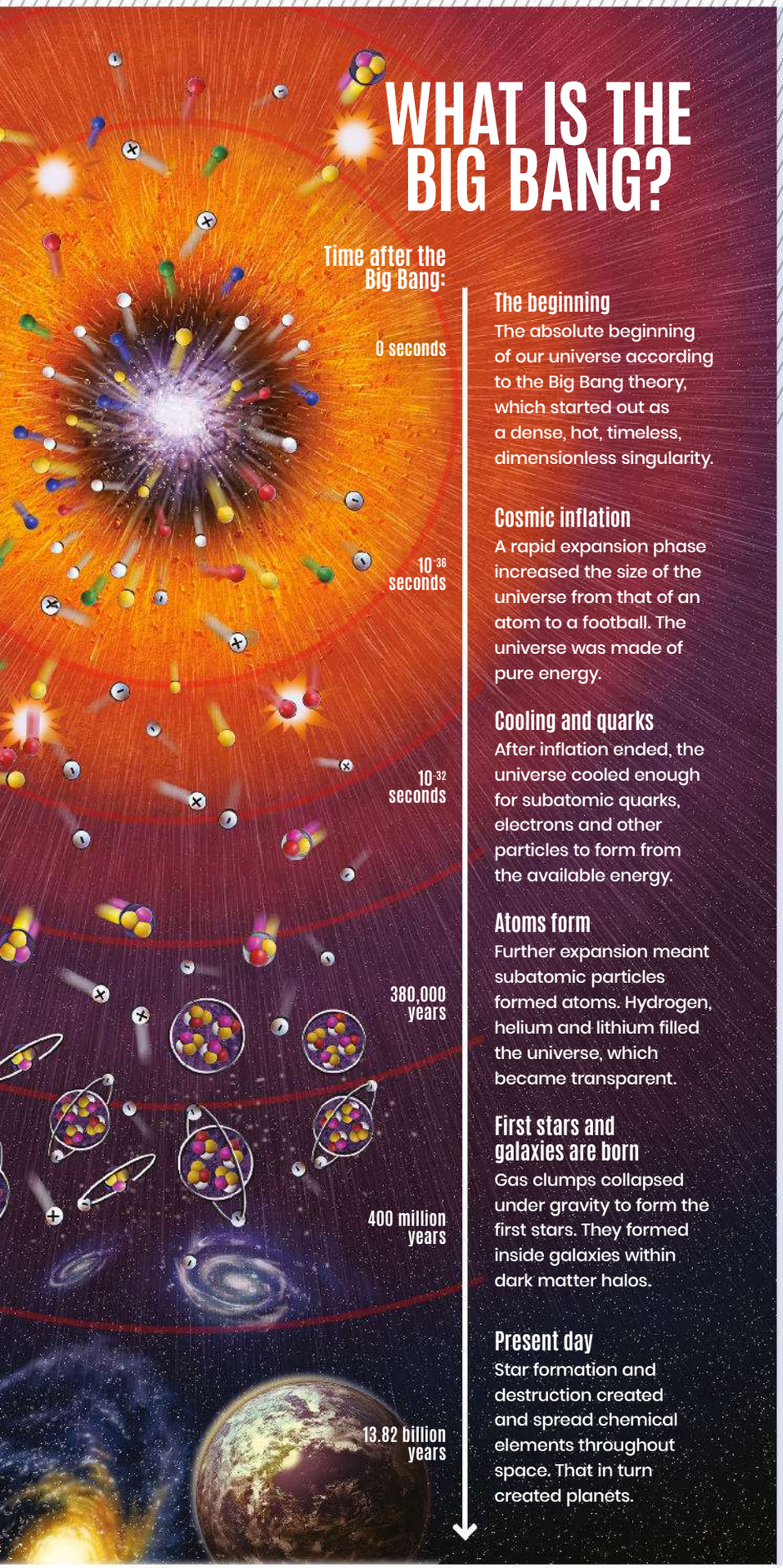
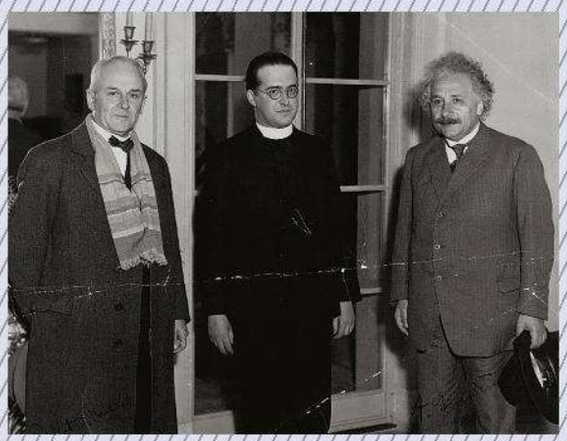

WHAT IS THE BIG BANG?
Time after the Big Bang:
0 seconds
10-36 seconds
10-32 seconds
380,000 years
400 million years
13.82 billion years
The beginning
The absolute beginning of our universe according to the Big Bang theory, which started out as a dense, hot, timeless, dimensionless singularity.
Cosmic inflation
A rapid expansion phase increased the size of the universe from that of an atom to a football. The universe was made of pure energy.
Cooling and quarks
After inflation ended, the universe cooled enough for subatomic quarks, electrons and other particles to form from the available energy.
Atoms form
Further expansion meant subatomic particles formed atoms. Hydrogen, helium and lithium filled the universe, which became transparent.
First stars and galaxies are born
Gas clumps collapsed under gravity to form the first stars. They formed inside galaxies within dark matter halos.
Present day
Star formation and destruction created and spread chemical elements throughout space. That in turn created planets.



did it take such a hold in cosmology? In 1912, American astronomer Vesto Slipher saw that the spectra of galaxies were Doppler shifted towards the red end of the electromagnetic spectrum. This showed they were moving away from us at speed. Then, in the 1920s, Alexander Friedmann, a mathematician in the Soviet Union, and Belgian astronomer Georges Lemaître both independently proposed the idea of an expanding universe, which could explain Slipher's observations. But reception to the idea was lukewarm. Even Einstein – upon whose general theory of relativity their hypothesis was based – didn't accept the idea at first.

In 1929, Edwin Hubble showed that the recession speeds of galaxies actually increased with their distance from Earth. This meant that if the universe was a movie played backwards, all galaxies would have once 'existed' at the same point in space and time. Friedmann and Lemaître were vindicated, and the speed-distance relationship became known as 'Hubble's law'. In light of all this, English astronomer Arthur Eddington invited Lemaître to speak in London, calling his solution 'brilliant'. Lemaître posited the idea of a universe expanding from a single point, which he described as a 'primeval atom' or an 'exploding cosmic egg'. This is what cosmologists now call the initial singularity, the point of the Big Bang – although it wasn't actually an atom, or an egg.

Unlike Einstein and others, Hoyle actually had no problem with an expanding universe. What he hated was the idea of a 'beginning'. As an avowed atheist, Hoyle couldn't accept a point of creation, and thus a potential 'creator'. He clung doggedly to steady-state theory: the idea that the universe had always existed and was perpetually creating and destroying. But Hoyle was on the losing team. In 1948, American cosmologists Ralph Alpher and Robert Hermann predicted a background radiation to space – the residual heat 'echo' just before the universe became transparent 380,000 years after the Big Bang. As space had expanded for billions of years since, this radiation's wavelength should have been stretched into the microwave region.

Just 14 years later it was finally discovered by Arno Penzias and Robert Wilson using the Holmdel Horn Antenna. Initially believing it to be caused by bird

droppings, they soon saw the spectrum of this cosmic microwave background (CMB) matched the predictions of the Big Bang model. Steady-state theory had no explanation for the CMB, and was therefore royally defeated. Alongside the work of Slipher, Friedmann, Lemaître and Hubble, Penzias and Wilson's evidence showed the universe had an origin after all and had been expanding. Big Bang theory was king.

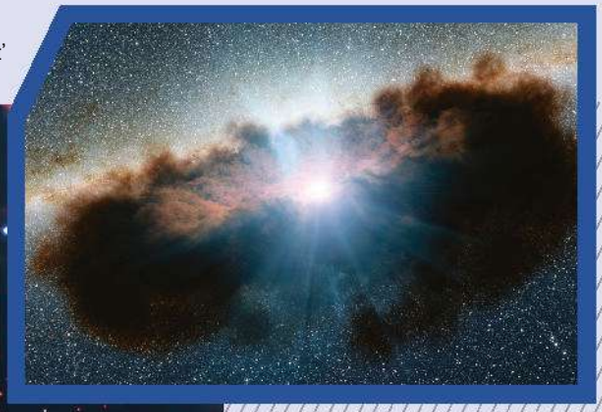
And yet despite its enormous success, there's always been something that scientists have never liked about the Big Bang: it doesn't explain the initial singularity. Where did it come from? Why is it simply assumed to have been timeless, dimensionless and infinitely dense? Scientists hate assumptions, especially regarding the big questions. Even cosmic inflation theory, developed by physicists Alan Guth, Andrei Linde and Paul Steinhardt, which successfully ironed out some of the problems of the Big Bang, couldn't explain the singularity. As a result, alternatives to these cosmological cornerstones have been proposed, and it's from this that the idea of a pre-Big Bang existence has arisen. Strangely, these ideas may even be supported by the very same CMB data that supports the Big Bang theory.

In 2001, Steinhardt worked with Neil Turok, Justin Khoury and Burt Ovrut on the 'ekpyrotic' model of the universe – an alternative to inflation. In their original hypothesis, the universe was birthed from a collision between two multidimensional membranes, or 'branes', floating through a higher dimension of space. After the universe was created from the collision, the ekpyrotic phase would occur. This would also apply to a contracting brane. Imagine a prolonged contraction of a previous universe eventually collapsing back into a singularity before restarting again as our present universe in a typical 'Big Bang' scenario. The conditions for our universe – its fundamental laws and seeds for a future large-scale structure – would have been set in the previous universe, and not by inflation. This scenario seems quite exotic, but more up-to-date forms of the ekpyrotic model mostly do away with these multidimensional branes and other exotica. The newer models simply apply the physical constraints of the Big Bang theory.

A researcher working with one such form of the ekpyrotic scenario is Dr Yi-Fu Cai of McGill University in Canada. He says: "Since Neil, Paul et al proposed their original scenario, the physical picture is very clear. Their cosmological model is able to dilute unwanted relics [of the Big Bang] via the 'ekpyrotic phase'. But the universe is still expected to pass directly through the singularity from the contracting to expanding phases without that being removed." What he means is that in the multidimensional scenario, although ekpyrosis can 'smooth out' some problems like cosmic inflation can, the singularity is still present and the physics surrounding that are as problematic as ever. But Cai's work, performed with Professor Robert Brandenberger, head of McGill's high-energy theory group, does away with singularities entirely.

In their model, a previous universe collapsed until it could go no further and then 'bounced' out as a new universe. "In our scenario, the whole of cosmic evolution then becomes smooth. The physics around the bounce, including the CMB and perturbation, are well-controlled and calculable," he says. By removing the singularity, a lot of associated problems are also removed. Cai and Brandenberger's work also predicts the existence of the CMB and the microscopic perturbations that grow to become the universe's large-scale structure. This is even consistent with data from the WMAP and Planck probes. Could the CMB contain hints of a previous universe that we could detect?

Many cosmologists have asked that very question. One scenario that has an answer is a cyclic model of cosmology. With their concept of universes perpetually oscillating between expanding and contracting phases, cyclic cosmological theories have a lot in common with 'Big Bounce' models. The idea has been around since at least the



Supermassive black holes may be gateways to other universes

Once atoms formed in the early universe, the resulting gas clouds collapsed to form stars

© NASA

WHAT CAUSED THE BIRTH OF THE UNIVERSE?

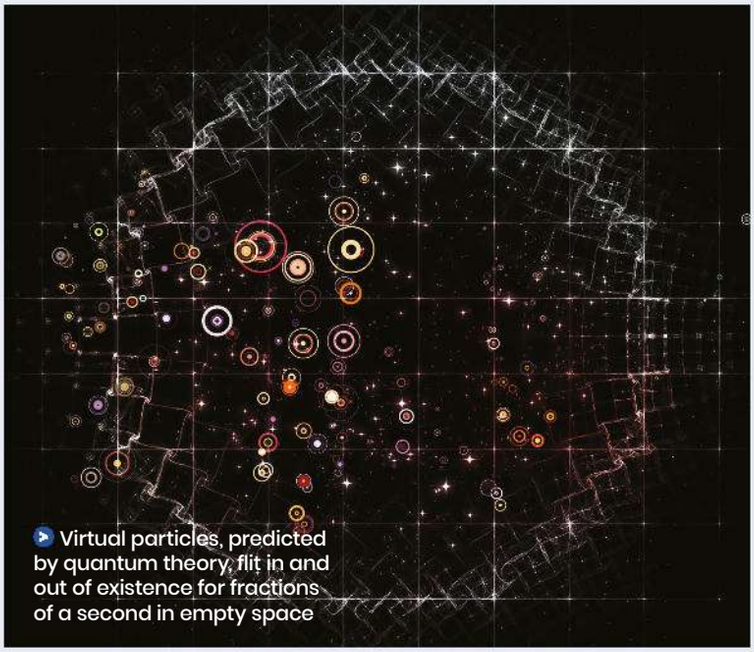
Many scenarios illustrate how our universe may have come into being

1 THERE WAS NOTHING

Strictly speaking, no scientist believes that our universe started from literally nothing. There always has to be something to cause another action to occur. However, many cosmologists are not yet convinced that there was anything before the Big Bang. Lawrence Krauss is one such scientist, and he's developed a theory of 'quantum nothingness' from which the universe could have originated.

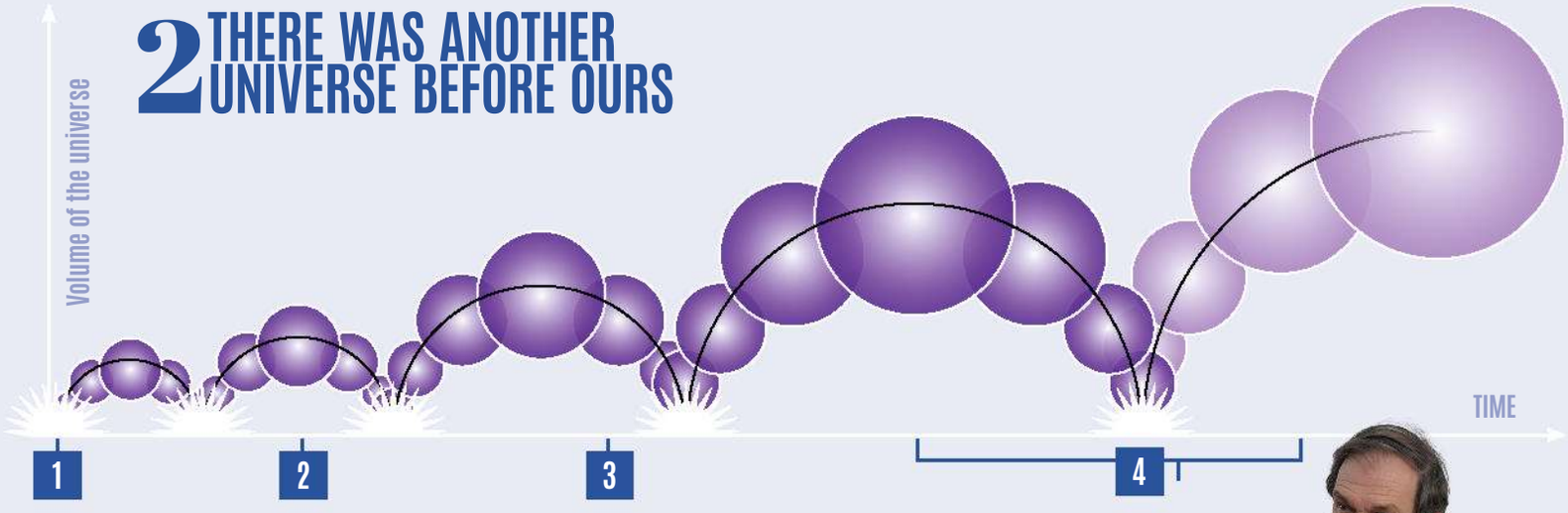
The theory involves so-called 'virtual particles' that flit in and out of existence for fractions of a second in empty space. They are predicted by quantum theory and their effects can be observed. Krauss says that if you remove virtual particles from a region of space it still has an energy density – but it shouldn't. It's from this form of 'nothing' that our universe could have started.

BACKED BY
Lawrence Krauss
Origins Project Foundation



Virtual particles, predicted by quantum theory, flit in and out of existence for fractions of a second in empty space

2 THERE WAS ANOTHER UNIVERSE BEFORE OURS



1 Big Bang and expansion

In the cyclic model, a universe may have a true origin as normal and go through an inflation and expansion phase.

2 Everything now stalls

In a cyclic universe the cosmos may expand to a point and then stall. This may happen from the gravitational effect of the matter within it.

3 Universe in reverse

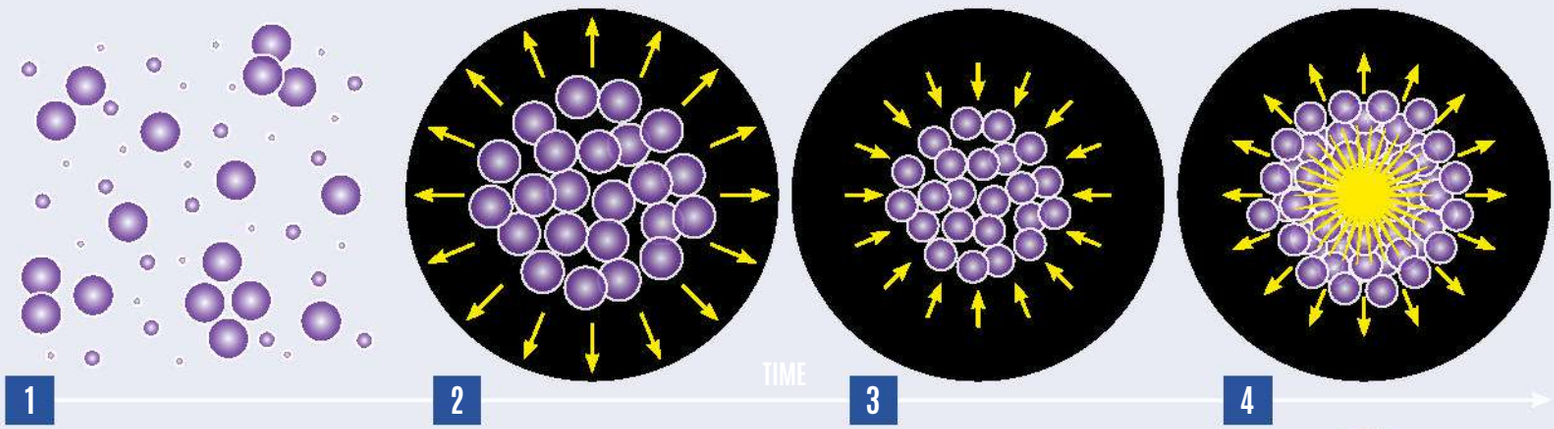
Gravity takes over and the universe now contracts, with galaxies moving towards one another instead of further away.

4 Big Bounce and the next phase

Inevitably, the universe can only contract so far. A 'Big Bounce' initiates the next expansion phase. The process continues, with each phase getting larger and slower.

BACKED BY
Sir Roger Penrose
Oxford University and Wadham College

3 IT'S ALWAYS BEEN THERE



1 An empty, infinite universe
In this scenario, the universe has existed forever and was nearly empty for that time. Then gravity took over and matter started to clump together.

2 Expanding internal region
The density of matter is such in some regions that it forms an incredibly massive black hole, the internal region of which experiences expansion.

3 A Big Crunch
Inside the huge black hole, matter again collapses under the intense gravity and increases in density up to a limit imposed by physics.

4 The Big Bang
When it can't stand any more, quantum fluctuations cause the matter to expand outwards in a typical Big Bang scenario within its black hole universe.

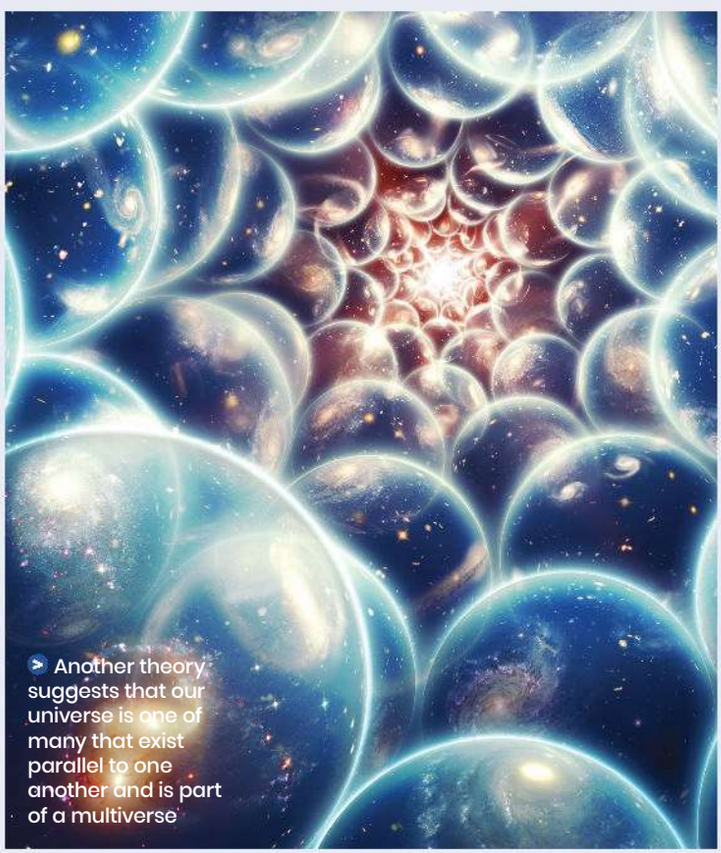
BACKED BY
Gabriele Veneziano
CERN and Collège de France

4 IT'S ONE UNIVERSE OF MANY

Eternal inflation theory was proposed in 1983 by physicist Paul Steinhardt as an extension of the cosmic inflation and Big Bang theories. Alan Guth, Andrei Linde and Steinhardt originally developed cosmic inflation theory to explain some problems with the Big Bang model, and it involved an exponential but rapid expansion of our universe.

The cause of cosmic inflation still remains somewhat vague, but for eternal inflation, Guth proposed in 2007 the existence of a 'false vacuum' or region of space with a positive energy density – similar to expanding bubbles forming in a boiling liquid. In this manner, certain regions of space-time, or 'universes', would be affected by their own form of cosmic inflation before the positive vacuum moved on to another region. As of yet, this scenario lacks evidence, but if true then our universe could exist as a nodule on another universe as part of a 'multiverse'.

BACKED BY
Professor Alan Guth
Massachusetts Institute of Technology



Another theory suggests that our universe is one of many that exist parallel to one another and is part of a multiverse

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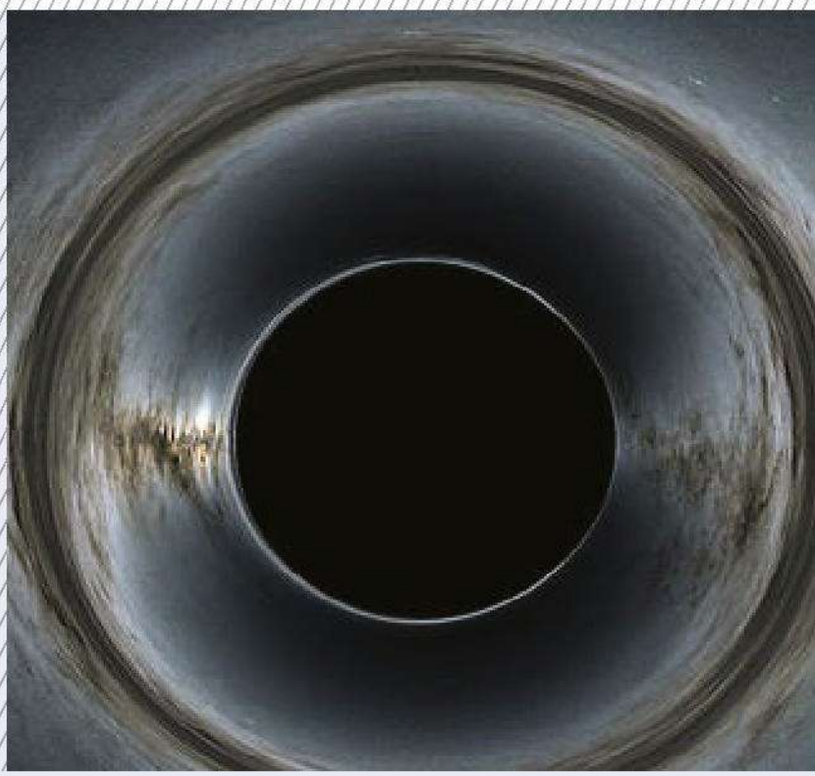

Could our entire universe live inside a black hole?

1920s, and one variant was even proposed by Einstein in 1930 after accepting Hubble's observations supporting an expanding universe. In the cyclic scenario, after an expansion phase the universe would slow, then stall, and would then contract back due to the gravitation of all the matter within it. This would culminate in a 'Big Crunch' or a 'Big Bounce', which would then be followed by a new expansion phase and so on. Einstein thought that this cyclical scenario could be a better, more long-term alternative to the simpler idea of an expanding universe with a single origin point.

But in 1934 American physicist Richard Tolman showed that such cyclic models couldn't work the way people wanted them to because of the second law of thermodynamics. Over time, the amount of entropy in an oscillating universe would only increase, and the amount of usable energy within it would only decrease. Every expansion would be slower and larger than the previous one, as each contraction phase would only go back so far and less energy would be available for each new expansion phase. Conversely, previous phases would have started out smaller and smaller until you eventually returned to a 'Big Bang' scenario again anyway. But in the age of WMAP and Planck, the idea of cyclic, oscillating universes has re-emerged. One example, conformal cyclic cosmology (CCC), was developed by English physicist Sir Roger Penrose and Armenian mathematician Vahe Gurzadyan in 2010 and is based on the theory of general relativity. Using data from both WMAP and Planck and also the BOOMERanG (Balloon Observations Of Millimetric Extragalactic RAdiation aNd Geophysics) experiment, Penrose and Gurzadyan published results that purported to show extremely faint concentric rings from previous cosmic cycles in CMB fluctuations – similar to ripples spreading out when you throw a stone into a pond. According to CCC, what we think of as the universe, the region that we can observe, anyway, is simply an 'aeon' or domain within an infinitely larger space-time.

Eventually, far into the future, once all the stars and galaxies have died out, all matter has dispersed and the supermassive black holes that lay at the centres of galaxies have evaporated, our aeon will have become completely smooth. But it will continue to expand and birth a new, larger scale aeon. CCC theory, which unlike previous cyclic models has no contraction phases, states that what we think of as inflation is simply the accelerating expansion of a previous aeon. But other cosmologists looking for concentric rings in the CMB haven't found anything significant yet. This may be because they used standard simulations to check against, whereas Penrose and Gurzadyan adopted a nonstandard approach.

Cyclic models like CCC remain controversial, and the Big Bang theory itself still has support. Physicist Lawrence Krauss wrote in 2012 that "the Big Bang picture is too firmly grounded in data from every area to be proven invalid in its general features". So could it be the true picture of the universe after all? Nikodem Popławski, a physicist at the University of New Haven, Connecticut, has developed a theory stating our universe originated from a black hole. Such extraordinary hypotheses have been a topic of speculation for years. "Our universe should obey the same laws as the parent universe in which the black hole exists," he says, adding that it should be possible to determine the size of the parent black hole by measuring temperature fluctuations in the CMB. "I published a paper that shows consistency with Planck's observations of the CMB. It also shows they aren't too sensitive to the black hole's initial size," he says.

> **"Our universe should obey the same laws as the universe in which the black hole exists"**
> **Nikodem Popławski**

And Popławski is now working on finding evidence for a black hole origin scenario. "If our universe was formed by a 'Big Bounce' in a black hole, its early expansion has specific dynamics that can be tested by measuring temperature fluctuations in the CMB from all directions in the sky," he says. Intriguingly, predictions that Popławski and his colleague Shantanu Desai of Garching, Germany, made of CMB fluctuations are consistent with the latest Planck data. And black holes rotate, so if our universe really was birthed from one, Popławski expects to see those effects, too. Echoing late cosmologist Stephen Hawking, he says: "Our universe could be the interior of a black hole existing in another universe. Black holes forming from stars and galaxies in such a universe create new universes. And so a universe can parent billions of baby universes, which are formed through black holes."

Kulvinder Singh Chadha
Space science writer
Kulvinder is a freelance science writer, outreach worker and former assistant editor of *Astronomy Now*. He holds a degree in astrophysics.

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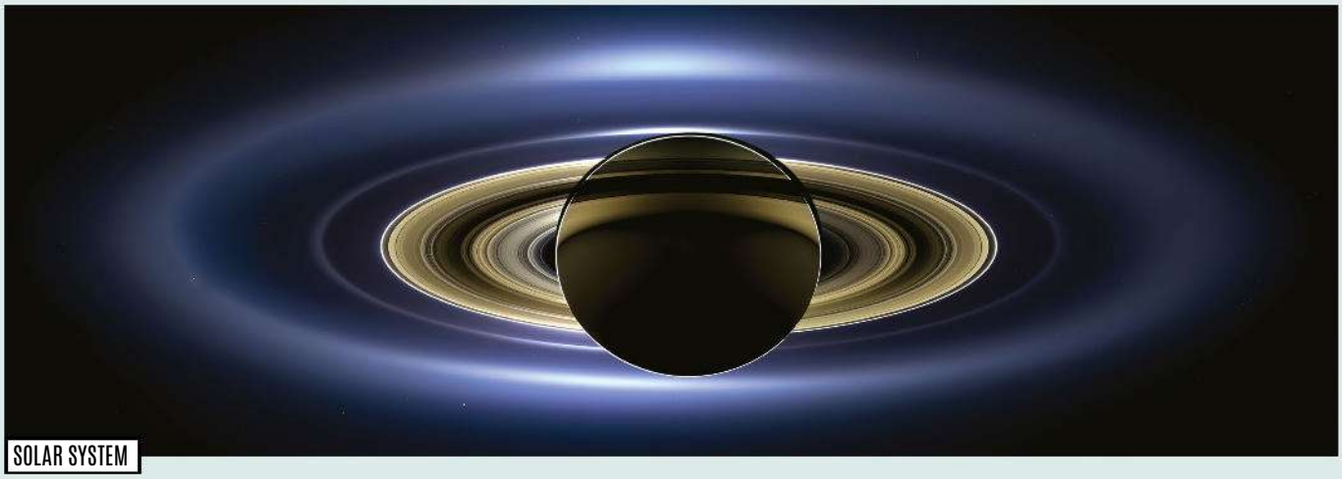
ASTROPHYSICS

What creates gravitational waves, and can we feel them?

Gravitational waves are vibrations in space-time itself. They are emitted by almost anything that moves, like planets orbiting or even your hands. However, only the most extreme phenomena in the universe can produce gravitational waves strong enough to be perceived. So far we have only detected extreme objects like black holes and neutron stars, and only when they're orbiting each other closely or merging.

As gravitational waves pass, they cause minute distortions in relative distances between objects. To feel this event in our body we would need to be quite close to the black holes. Instead we can use technology to record fainter signals from distant galaxies. The Laser Interferometer Gravitational-Wave Observatory (LIGO) and Virgo detectors have lasers and mirrors arranged to measure a relative stretch or contraction of minuscule amounts – less than the size of a proton over the four-kilometre (2.5-mile) length of the arms. It's no surprise that the first detection took a century since Einstein first predicted them.

Dr Miguel Zumalacarregui, Max Planck Institute for Gravitational Physics



SOLAR SYSTEM

How did Saturn get its rings?

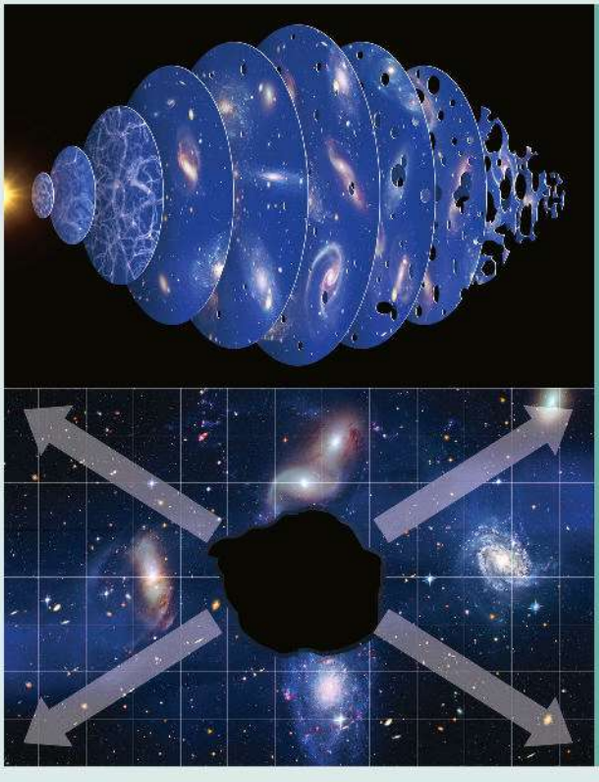
Imagine two ring particles – little chunks of ice – in contact with each other near Saturn. The planet's gravitational attraction is a little stronger on the particle closer to Saturn. This difference is called a tidal force, and is closely related to the tides in the oceans. Because of tidal forces, it's difficult or impossible for a moon to form very close to a planet.

Saturn's rings are probably the remnants of a large icy body that formed elsewhere and was ripped apart when it came too close to Saturn. In one scenario, a moon like Titan spiralled in through the disc of gas and dust that surrounded the young Saturn. The moon's icy shell could have been torn off, with the fragments going into orbit around Saturn and the moon's rocky core being swallowed by the planet. The icy chunks would have collided and spread, with the particles close to Saturn becoming the ring system and those that moved farther out coagulating into moons. In another model, a large centaur – a body that escaped the Kuiper Belt – was torn apart by Saturn's tidal forces during a chance, very close passage. In a third concept, a moon of Saturn was destroyed by a comet impact. As in the first model, the fragments in these scenarios would have collided and formed rings and moons. Though the Cassini orbiter vastly expanded our understanding of Saturn's rings, we still don't know which of these ideas is correct.

Luke Dones, senior research scientist at Southwest Research Institute, Colorado

A Saturn's rings consist of mostly ice, rock and dust

B The 'Big Rip' could potentially tear the whole of space and time apart



ASTROPHYSICS

Given the universe's acceleration, could it end in a Big Rip?

We are currently living in a universe in accelerated expansion, which means that objects in the universe recede away from us with a speed that grows with the distance. Even if we waited an infinite amount of time, we would never be able to observe beyond some distance because objects very far away from us are receding away from us so fast that neither light, nor gravitational waves nor any other type of information emitted by those objects would ever be able to reach us.

We know that the expansion of the universe is accelerating, but if the acceleration was itself speeding up, then the size of the observable universe would shrink and there would be a time where the observable universe would be so small that we wouldn't even be able to see our neighbouring galaxies. When the size of the observable universe is even smaller than the minimal length we can conceive, this would correspond to a Big Rip, possibly tearing apart the whole structure of space and time.

Claudia de Rham, professor of theoretical physics at Imperial College London

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ASTRONOMY

Why do we use radio to observe the universe?

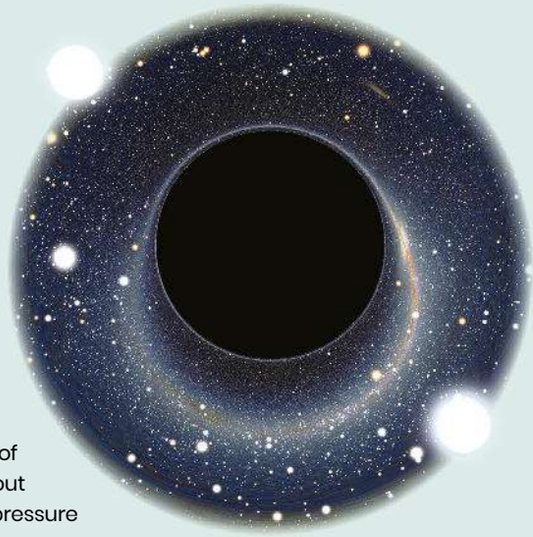
There's particular science that can only be done in radio wavelengths, and you just need to look back at the last 30 or 40 years or so of astronomy; a lot of the big discoveries have been made at radio wavelengths. Particularly pulsars, which were discovered in the UK, could not have been done in any other wavebands. I'd say that this is a very big example of needing to study the universe in radio wavebands.

Things like looking at complex molecules, which are very interesting for people looking for life in the universe, is another example, and one which is going very well in radio wavelengths. And looking back in time is also very good in long radio wavelengths, since they can see through all of the obscuring matter in space in order to go way back to the beginning of the universe, which can be very hard to do at optical wavelengths and other wavelengths. It's the way that a lot of astronomy has been done.

Tyler Bourke, senior scientist for the Square Kilometre Array

ASTROPHYSICS

Why don't all stars eventually turn into black holes?



It's all to do with mass. During its life, a star exists in a balance between the force of gravity, which pulls its material towards its centre, and the outward pressure that material exerts when compressed. Towards the end of a star's life, the balance between these two forces shifts in favour of gravity. This often happens because the star runs out of nuclear fuel, resulting in less outward radiation pressure and less gas pressure.

However, as gravity becomes more important, it compresses the material at the centre, heating it and increasing the outward pressure once more. In more massive stars, gravity ultimately wins and compresses the star until it is as dense as physically possible, resulting in a black hole. On the other hand, less massive stars have weaker gravitational pulls, and in the end a new balance is struck which allows these stars to support themselves against gravity indefinitely as a dead ball of nuclear ash. Occasionally, something even more unusual happens. For stars in a certain mass range, no new balance is struck, but no black hole is formed. In these cases, the star explodes entirely, scattering its matter in all directions and leaving absolutely nothing 'stellar' behind.

Dr Adam Jermyn, former fellow at the Flatiron Institute's Center for Computational Astrophysics

A The deciding factor in a star's future is its mass

V The size of a star depends on how much material it absorbed from dust clouds and gases in space

ASTROPHYSICS

Why do stars have different masses?

Stars have different masses because they are born that way, unlike humans, who continue to gain weight throughout their lifetimes. The difference lies in the fact that stars gain all their mass at birth when they accrete nearby material in their gravitational influence until there is no more material left, whereas humans 'accrete' food whenever their appetite says so!

Stars generally have masses between one-tenth and a few hundred times the mass of the Sun. At the low end, stars with insufficient mass do not burn hydrogen because there is not enough mass to compress the material in their cores to high enough pressures. At the high end, it is not clear what limits the masses of stars. Some astronomers claim that there is an upper limit of around 150 times the mass of the Sun, although other astronomers believe that there is no limit, or that the limit is higher.

© ESO

Donald Figer, director of the Future Photon Initiative and the Center for Detectors at the Rochester Institute of Technology

EXOPLANETS

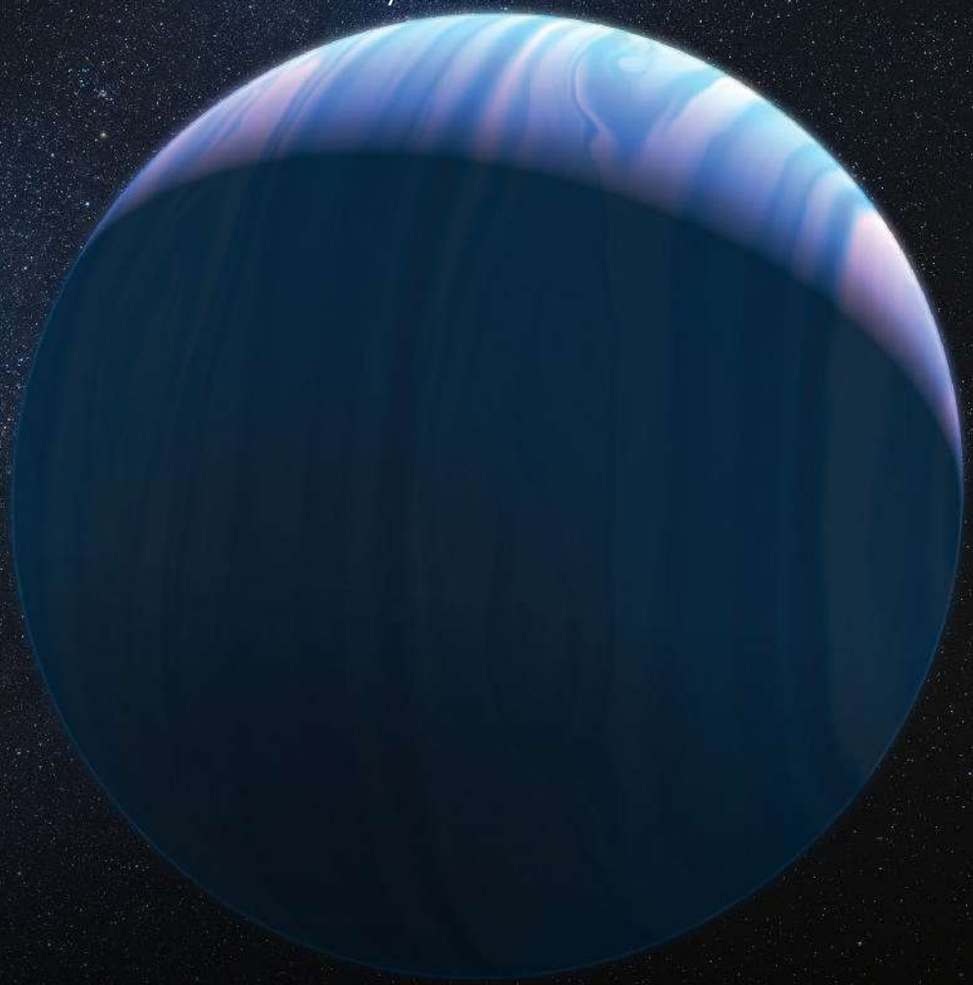
Would it be possible to survive on a planet around a double-star system?

Tatooine-like planets, those orbiting around double or binary stars, also known as circumbinary planets (CBPs) – are no longer just science fiction. The Kepler spacecraft observed several transiting CBPs. Here we focus on circumbinary-type planets that move around the centre of mass of the double-star system in a relatively wide orbit.

The first requirement for survival on a CBP is that the planet remains dynamically stable. Gravitational perturbations from the binary can destabilise the circumbinary orbit. If this happens then the CBP is likely ejected from the system, or it could even collide with one of the stars. Both are not favourable scenarios for survivability. Secondly, if we agree to need liquid water for survival, and ideally a breathable atmosphere, the CBP should neither be too close nor too far from the binary.

Even if we manage to find a habitable CBP, it's not guaranteed to stay habitable indefinitely. Over timescales of billions of years the binary stars – assuming they are similar to the Sun – will evolve. In later stages the stars will lose a lot of mass when they evolve into white dwarfs. The mass loss could unbind the CBP, hurtling it into the darkness of space. If not, the dim light from the white dwarfs would usher in an indefinite ice age. We are fortunate to be living on a planet that, for now, is very accommodating to life.

Adrian Hamers, postdoctoral fellow at the Institute for Advanced Study in Princeton, New Jersey



Did you know?

Most stars form in binary pairs because they spin so quickly as they form that their surfaces reach escape velocity before they finish collapsing, creating a pair.

© ESO; jodrellbank; Source: Wikipedia Commons; Alain r

WHAT'S IN THE SKY?

What to look out for during this observing period

In this issue...

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85 Naked eye and binocular targets As Christmas looms on the horizon, relax by enjoying these celestial treats

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1 DECEMBER
Asteroid 349 Dembowska will be well placed for observation in Taurus

1 DECEMBER
Mars will reach its closest point to Earth, or perigee

Red-light friendly
In order to preserve your night vision, you should read our observing guide under red light

2 DECEMBER
Conjunction of the Moon and Jupiter in Pisces

3 DECEMBER
Neptune ends its retrograde motion

5 DECEMBER
The Moon will pass in front of Uranus, creating a lunar occultation in Aries

6 DECEMBER
The phi Cassiopeiid meteor shower reaches its peak

8 DECEMBER
Mars will reach opposition in Taurus

8 DECEMBER
The Moon and Mars will pass within 0°32' of each other in Taurus

9 DECEMBER
The Moncerotid meteor shower reaches its peak

12 DECEMBER
The sigma Hydrid meteor shower reaches its peak

15 DECEMBER
Comet 81P/Wild will make its closest approach to the Sun in Virgo

21 DECEMBER
Mercury will reach its greatest elongation from the Sun at magnitude -0.6 in Sagittarius

26 DECEMBER
Mercury reaches its highest point in the evening sky

Naked eye | Naked eye warning (TAKE CARE!) | Binoculars | Small telescope | Medium telescope | Large telescope | Solar eclipse | Solstice

15 DECEMBER
Open cluster NGC 1981 is well placed for observation in Orion

16 DECEMBER
The Comae Berenicid meteor shower reaches its peak

20 DECEMBER
The Leonis Minorid meteor shower reaches its peak

24 DECEMBER
Conjunction between the Moon and Venus in Sagittarius

24 DECEMBER
Mercury will reach half phase, or dichotomy

26 DECEMBER
Conjunction between the Moon and Saturn in Capricornus

26 DECEMBER
The Moon and Saturn pass within 3°46' of each other in Capricornus

28 DECEMBER
Open cluster NGC 2232 is well placed for observation in Monoceros

29 DECEMBER
The Moon and Jupiter will make a close approach, passing within 2°02' of each other in Pisces

Jargon buster

Conjunction
An alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Declination (Dec)
How high an object will rise in the sky. Like Earth's latitude, Dec measures north and south in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and 60 arcminutes in a degree.

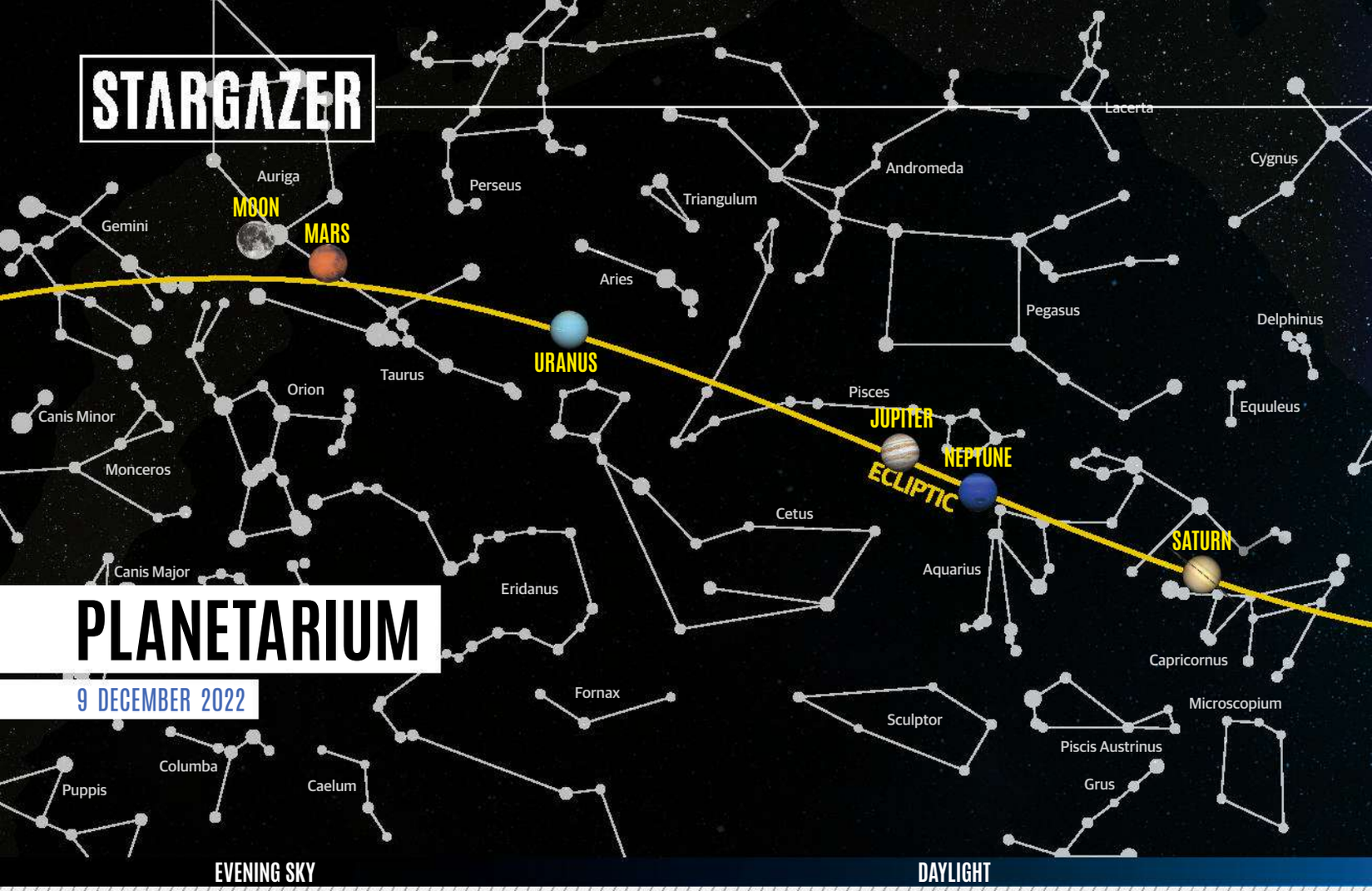
Opposition
When a celestial body is in line with Earth and the Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Right Ascension (RA)
RA is to the sky what longitude is to Earth, corresponding to east and west. It's measured in hours, minutes and seconds, as since Earth rotates on its axis, we see different parts of the sky throughout the night.

Magnitude
An object's magnitude tells you how bright it appears from Earth, represented on a numbered scale. The lower the number, the brighter the object. A magnitude of –1.0 is brighter than +2.0.

Greatest elongation
When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongation and as morning stars during western elongation.

Source: Wikipedia Commons © Roberto Mura; David St. Louis



MOON CALENDAR

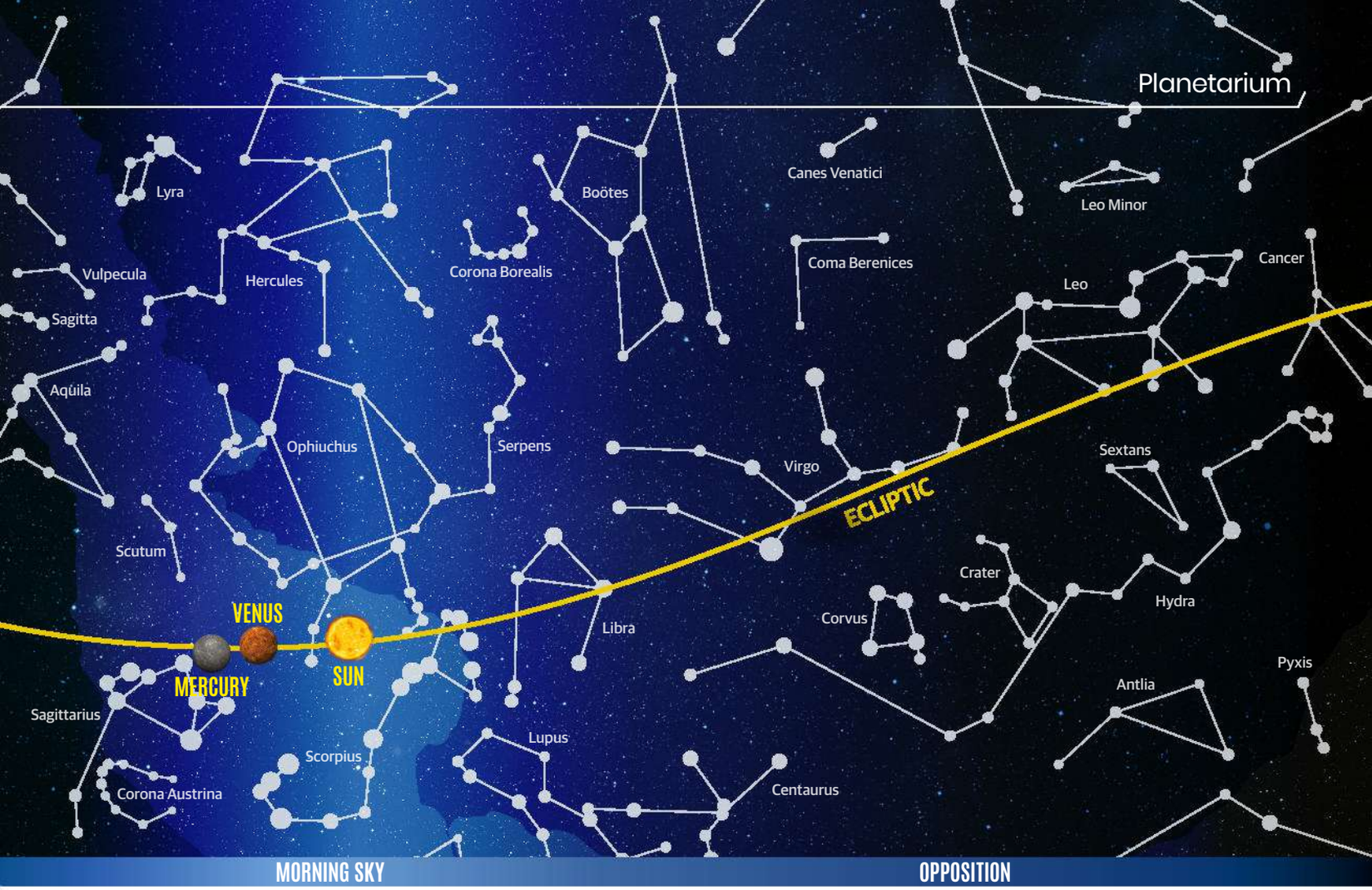
* The Moon does not pass the meridian on 8 December

2 DEC 73.4% 00:52 13:44	3 DEC 82.4% 02:11 13:56	4 DEC 89.7% 03:28 14:09	5 DEC 95.1% 04:45 14:25			
6 DEC 98.6% 06:02 14:43	7 DEC 99.9% 07:17 15:08	8 DEC FM --.--%* 08:29 15:40	9 DEC 99.2% 09:32 16:24	10 DEC 96.6% 10:24 17:19	11 DEC 92.2% 11:03 18:23	12 DEC 86.3% 11:32 19:33
13 DEC 79.0% 11:53 20:45	14 DEC 70.5% 12:10 21:57	15 DEC 61.2% 12:24 23:09	16 DEC TQ 51.3% 12:36 --:--	17 DEC 41.4% 00:22 12:47	18 DEC 30.9% 01:36 13:00	19 DEC 21.2% 02:55 13:14
20 DEC 12.7% 04:18 13:32	21 DEC 5.8% 05:47 13:57	22 DEC 1.5% 07:16 14:34	23 DEC NM 0.1% 08:38 15:29	24 DEC 2.1% 09:43 16:43	25 DEC 7.2% 10:29 18:12	26 DEC 15.0% 10:59 19:45
27 DEC 24.7% 11:21 21:14	28 DEC 35.5% 11:38 22:39	29 DEC 46.7% 11:51 --:--	30 DEC FQ 57.7% 00:00 12:04			

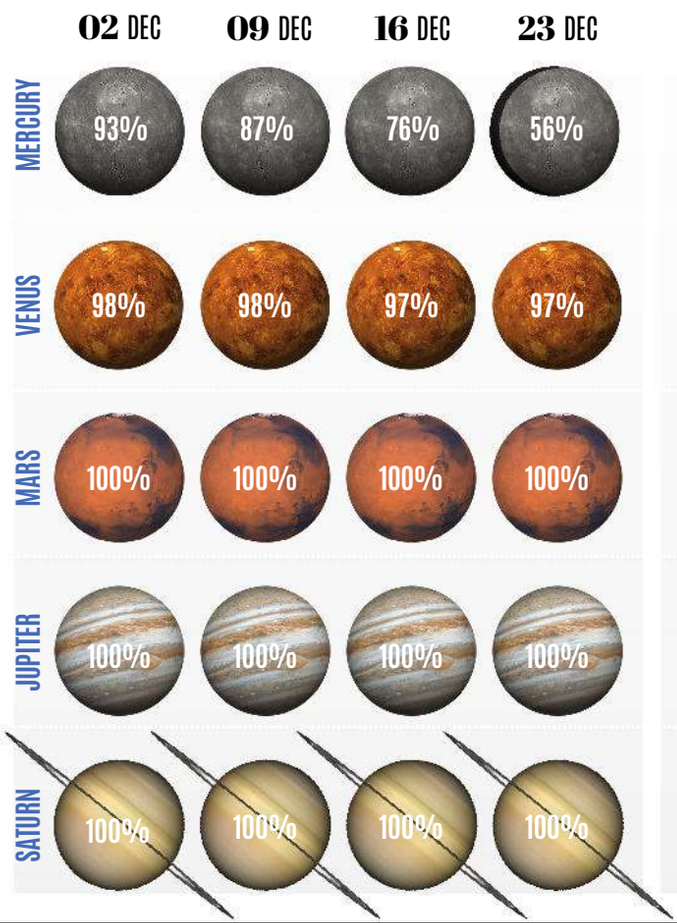
% Illumination
Moonrise time
Moonset time

FM Full Moon
NM New Moon
FQ First quarter
TQ Third quarter

All figures are given for 00h at midnight (local times for London, UK)



ILLUMINATION PERCENTAGE



PLANET POSITIONS

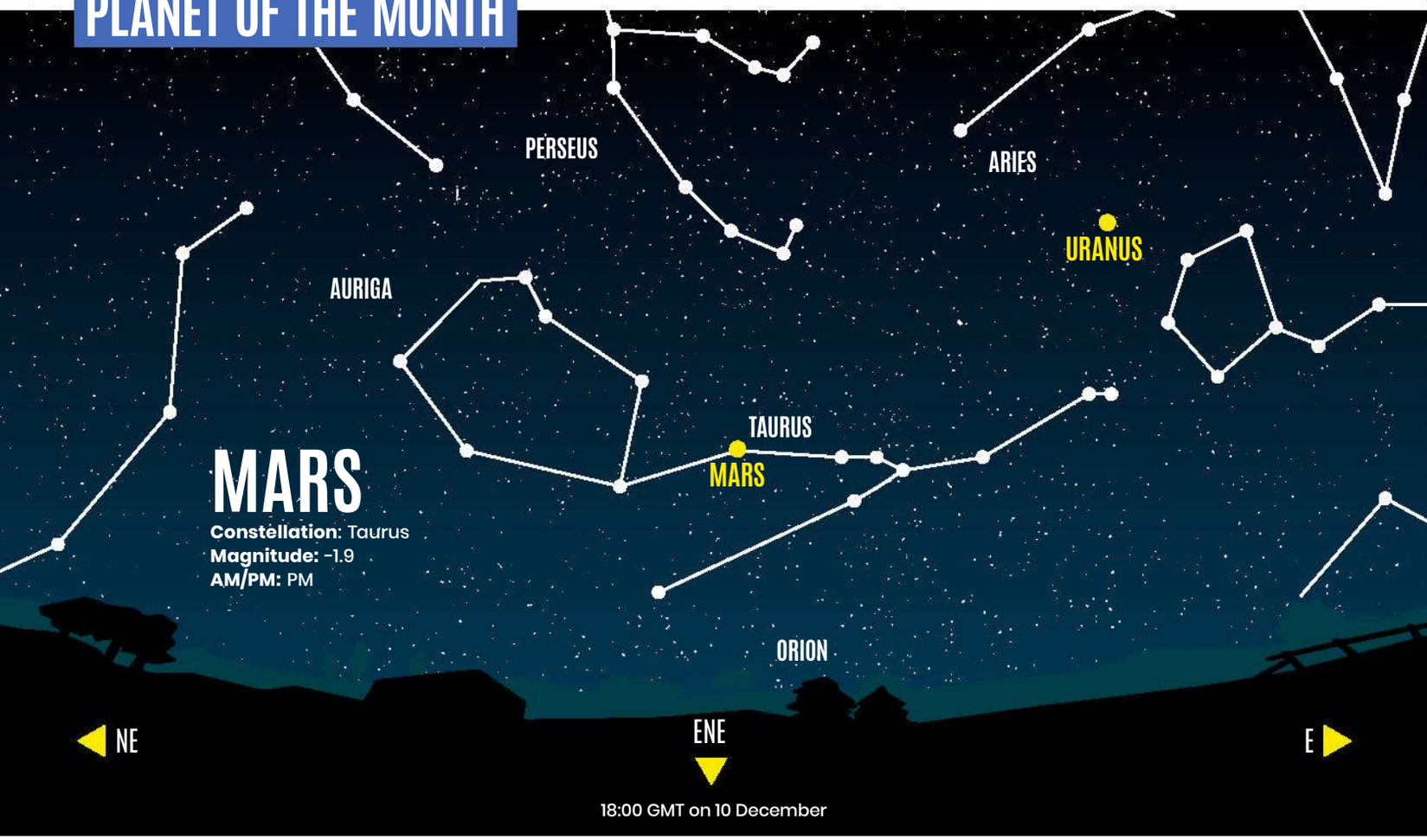
All rise and set times are given in GMT

DATE	RA	DEC	CONSTELLATION	MAG	RISE	SET
2 DEC	17h 25m 44s	−25° 16' 47"	Ophiuchus	−0.6	09:01	16:20
9 DEC	18h 12m 16s	−25° 43' 25"	Sagittarius	−0.6	09:23	16:35
16 DEC	18h 56m 05s	−24° 59' 29"	Sagittarius	−0.6	09:34	16:57
23 DEC	19h 30m 55s	−23° 13' 02"	Sagittarius	−0.6	09:29	13:23
30 DEC	19h 43m 22s	−21° 04' 04"	Sagittarius	0.5	08:59	17:16
2 DEC	17h 13m 55s	−23° 25' 58"	Ophiuchus	−3.9	08:36	16:21
9 DEC	17h 52m 12s	−24° 06' 41"	Sagittarius	−3.9	08:51	16:27
16 DEC	18h 30m 43s	−24° 11' 08"	Sagittarius	−3.9	09:03	16:37
23 DEC	19h 09m 04s	−23° 39' 02"	Sagittarius	−3.9	09:10	16:52
30 DEC	19h 46m 55s	−22° 31' 25"	Sagittarius	−3.9	09:12	17:10
2 DEC	05h 07m 48s	+24° 56' 58"	Taurus	−1.8	15:51	08:47
9 DEC	04h 55m 52s	+24° 57' 19"	Taurus	−1.9	15:13	08:09
16 DEC	04h 44m 31s	+24° 52' 16"	Taurus	−1.7	14:35	07:30
23 DEC	04h 34m 51s	+24° 43' 37"	Taurus	−1.5	13:59	06:52
30 DEC	04h 27m 42s	+24° 34' 28"	Taurus	−1.3	13:25	06:16
2 DEC	23h 57m 06s	−01° 51' 46"	Pisces	−2.6	13:16	01:05
9 DEC	23h 58m 04s	−01° 43' 22"	Pisces	−2.6	12:49	00:39
16 DEC	23h 59m 37s	−01° 31' 08"	Pisces	−2.5	12:22	00:14
23 DEC	00h 01m 44s	−01° 15' 18"	Pisces	−2.5	11:55	23:50
30 DEC	00h 04m 24s	−00° 56' 04"	Pisces	−2.4	11:29	23:27
2 DEC	21h 29m 42s	−16° 08' 08"	Capricornus	+0.8	12:05	21:22
9 DEC	21h 31m 36s	−15° 58' 36"	Capricornus	+0.8	11:38	20:58
16 DEC	21h 33m 46s	−15° 47' 51"	Capricornus	+0.8	11:12	20:33
23 DEC	21h 36m 09s	−15° 35' 55"	Capricornus	+0.8	10:46	20:09
30 DEC	21h 38m 45s	−15° 22' 57"	Capricornus	+0.8	10:20	19:46

THIS MONTH'S PLANETS

Mars reaches opposition, glowing like a ruby in the sky

PLANET OF THE MONTH



MARS

Constellation: Taurus
Magnitude: -1.9
AM/PM: PM

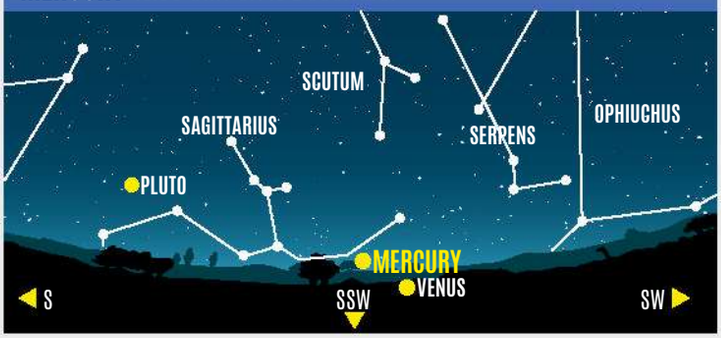
At the start of December Mars will be rising in the northeast at sunset. It will reach its highest point above the southeastern horizon around 23:00, then arc down to set in the west at sunrise, but all through December Mars will be a strikingly bright orange-red evening star, very obvious to the naked eye. Mars will spend the month in the constellation of Taurus, the Bull, which is dominated by two large and bright star clusters, the large, V-shaped Hyades cluster and the smaller Pleiades cluster, which looks like a mini Big Dipper.

During December Mars will be shining close to these two celestial celebrities, presenting naked eye observers, binocular users and night-sky photographers with quite a beautiful scene. At the start of the month Mars will be brighter and closer to us than it has been for two years as it reaches opposition. Because Mars will be brighter than the stars around it, it will be very easy to find, even if you don't know the night sky very well. Mars will be at its very best around 8 December, during its closest approach to Earth. Then it will shine at magnitude -1.9, far outshining any other star or planet around it. Unfortunately it will also be very close to the full Moon that night, so its brightness will be diminished by the Moon's glare, but it won't matter too much because Mars will still be easily visible to the eye, and within a few days the Moon will be out of the way, leaving Mars to blaze brightly on its own.

If you go outside late on Christmas Eve to give yourself a break from last-minute gift wrapping, you'll find that Mars will have faded slightly to magnitude -1.4, but that will still make it brighter than every star in the sky, including Sirius. You'll also see it is now forming a tight triangle in the sky with the Hyades and Pleiades clusters, close enough to ruddy Aldebaran, the brightest star in Taurus, to make the pair appear like an orange double star in the sky.

As December ends and the New Year beckons, Mars will have edged further towards the Pleiades star cluster and will be setting before the Sun rises. But even though it will be past its best for this opposition, the Red Planet will remain a lovely sight for every stargazer, from the absolute beginner standing in their garden, looking at it with just their eyes, to the experienced amateur gazing at it through the eyepiece of their telescope. Make sure you see it too.

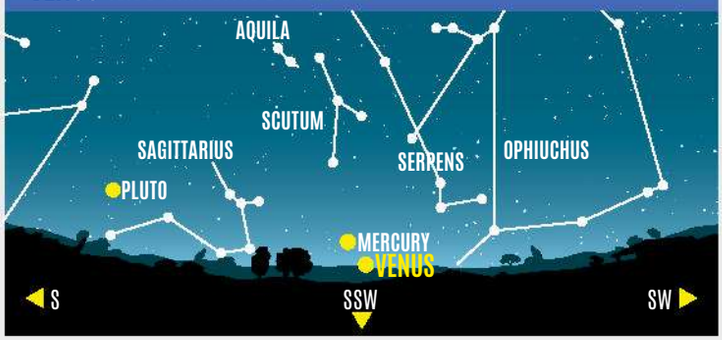
MERCURY 15:00 GMT on 10 December



Constellation: Ophiuchus **Magnitude:** -0.6 **AM/PM:** PM

At the start of the month Mercury will be an 'evening star' quite close to Venus, but it will be setting in the southwest just 20 minutes after the Sun, making it extremely challenging to see in the bright sunset sky. As the days pass Mercury will pull away from the Sun, so will be visible for a little longer each evening.

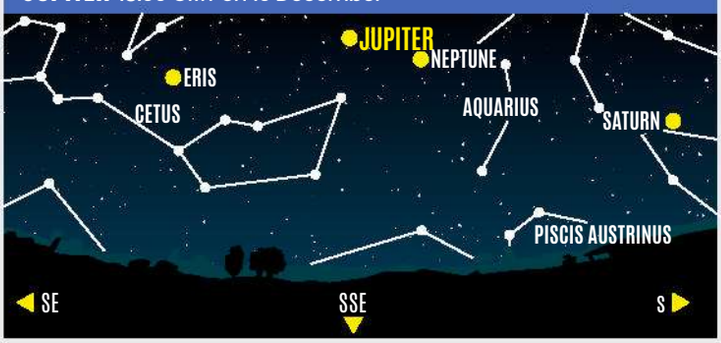
VENUS 15:00 GMT on 10 December



Constellation: Ophiuchus **Magnitude:** -3.9 **AM/PM:** PM

At the start of December Venus will be visible low in the southwest after sunset, but setting less than half an hour after the Sun. As the month progresses Venus will climb a little higher each evening, but it will never reach any great height, and if you have trees or hills to the southwest they will probably hide it from view.

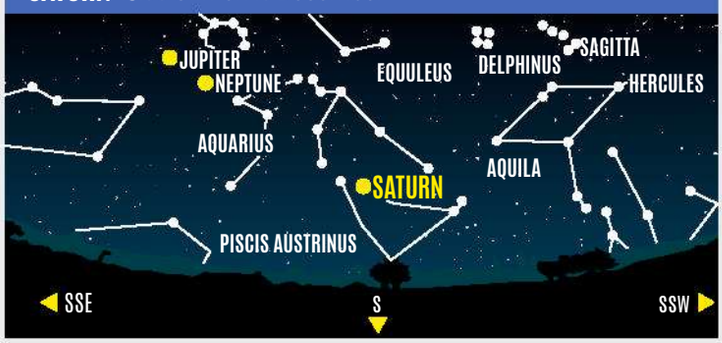
JUPITER 18:00 GMT on 10 December



Constellation: Pisces **Magnitude:** -2.6 **AM/PM:** PM

Jupiter is an evening object during December, easily visible to the naked eye through the night as a bright blue-white 'star' embedded in Pisces. On 1 December it will be visible low in the southeast as soon as the sky begins to darken after sunset, shining close to the Moon, and won't set until 01:00 the next morning.

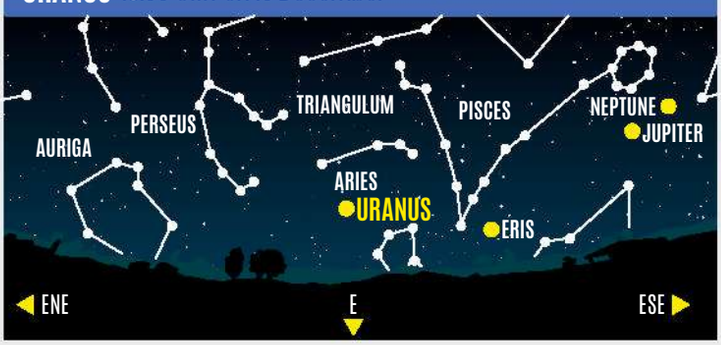
SATURN 18:00 GMT on 10 December



Constellation: Capricornus **Magnitude:** +0.8 **AM/PM:** PM

The Ringed Planet will be a naked-eye object all through December, looking like a warm yellow-white 'star' shining in the star-starved constellation of Capricornus. You will need to have a telescope if you want to see its famous rings, but binoculars will show you its largest moon, Titan.

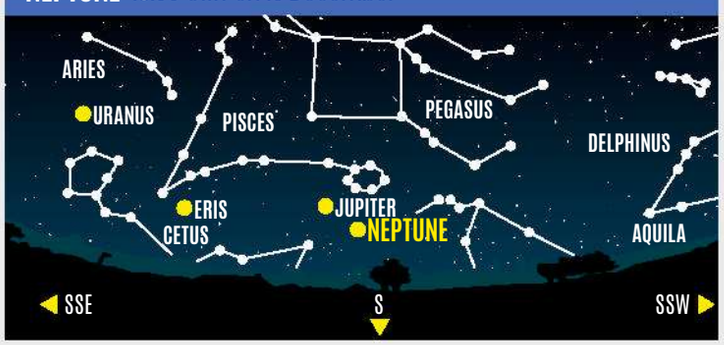
URANUS 18:00 GMT on 10 December



Constellation: Aries **Magnitude:** +5.6 **AM/PM:** PM

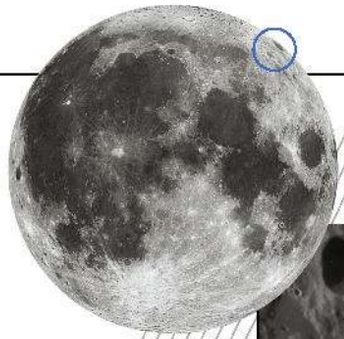
Uranus will be visible to the naked eye as a very faint 'star'. Before sunrise on 5 December Uranus will be occulted – or eclipsed – by the Moon as it passes behind its disc. You'll need binoculars or a telescope to see Uranus vanish behind the Moon at about 04:55 and reappear again on the other side around 25 minutes later.

NEPTUNE 18:00 GMT on 15 December



Constellation: Aquarius **Magnitude:** +7.9 **AM/PM:** PM

During December Neptune, the most distant planet in our Solar System, will be an evening 'star' close to Jupiter. At the start of the month the two worlds will be six degrees apart, and by the end of the month will have moved slightly further apart, with eight degrees separating them. You'll need a telescope to see Neptune.



MOON TOUR

MARE HUMBOLDTIANUM

Great views of the northeastern limb make this elusive lunar sea an intriguing target this month

TOP TIP!

You should observe this lunar sea when the Moon's northeastern limb is visible, between 1 and 8 December. A Moon filter will improve contrast.

This month we turn to the very edge of the Moon and take a look at one of the most elusive lunar seas visible from Earth – Mare Humboldtianum. Located on the Moon's northeastern limb, Mare Humboldtianum is a dark patch of ancient lava some 270 kilometres (170 miles) across on the lunar nearside. The sea's eastern edge just touches the 90 degrees east line of longitude.

Since the Moon rotates once on its axis in precisely the same time as it takes to revolve around Earth, keeping the same face turned towards us, it might be thought that Mare Humboldtianum should always be on view whenever it's illuminated by the Sun. But this isn't the case, owing to a phenomenon known as libration.

Libration produces an apparent slow rocking motion of the Moon, a phenomenon that allows a total of 59 per cent of the Moon's surface to be seen over time, while the remaining 41 per cent of the Moon – the true far side – is perpetually hidden from our gaze. Libration has a number of causes, but the main effect is caused by the Moon's elliptical orbit around Earth, combined with the steady rotation of the Moon on its axis each lunar month. Libration can bring features on the edge of the far side into our telescopic sights, and it can also work the other way, pushing features that are near the mean lunar limb out of sight – the latter applies to Mare Humboldtianum.

Under an unfavourable libration, where the Moon's southwestern limb is well-seen, Mare Humboldtianum is shunted onto and beyond the northeastern limb, rendering it virtually unobservable. However, a favourable libration, combined with a favourable illumination, brings the Moon's northeastern limb regions into view, and then Mare Humboldtianum is pretty easy to spot, even through binoculars. The latter circumstance takes place in December, so it's a great opportunity to take a look at one of the Moon's smaller and lesser known seas.

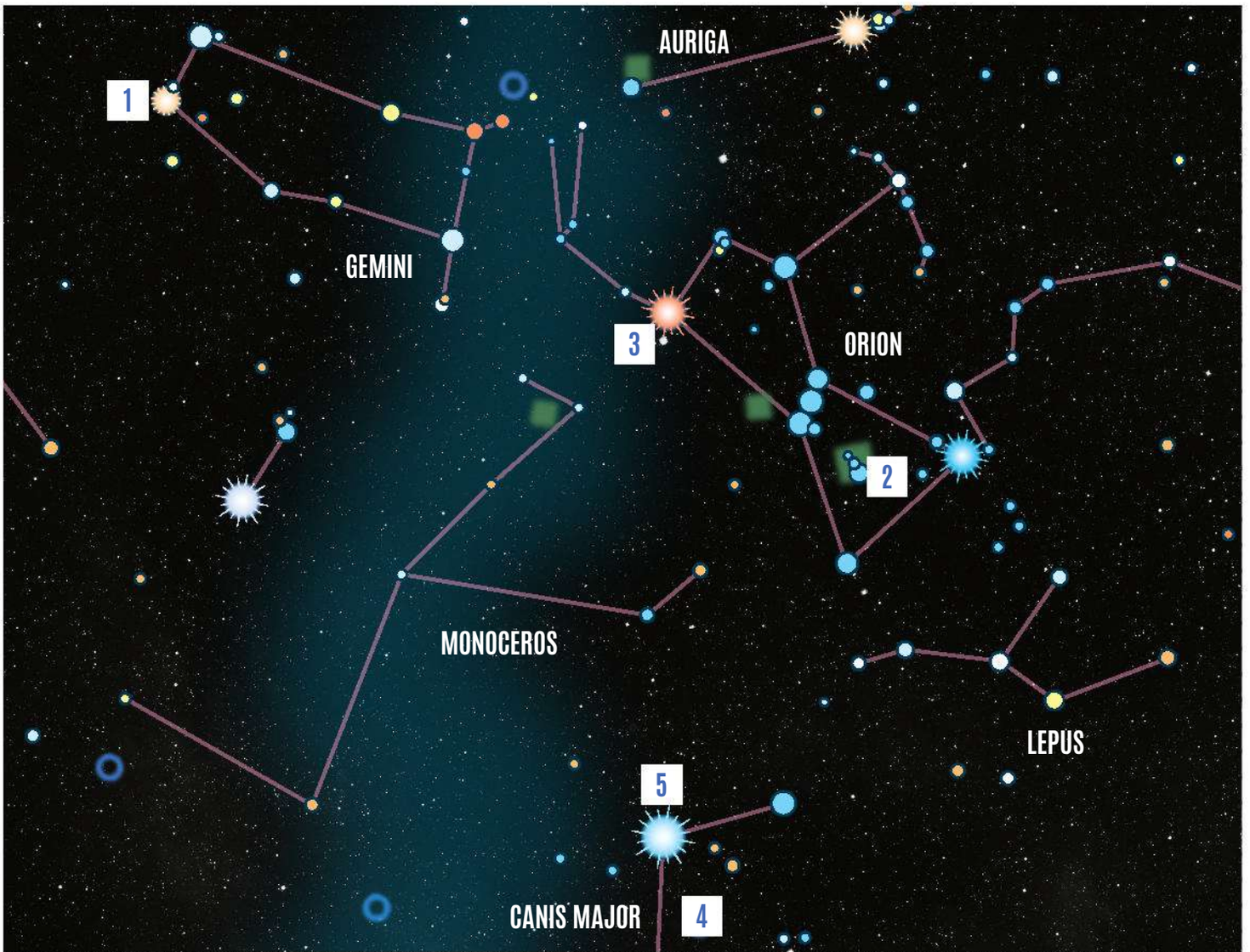
First, a little historical perspective. Mare Humboldtianum is a dark patch of ancient lava that's 270 kilometres (170 miles) across. It fills the central regions of a much larger ancient impact basin that's around 650 kilometres (404 miles) across, whose eastern reaches extend well onto the Moon's true far side. The basin-forming impact took place around 3.8 billion years ago.

Later lunar impacts have scarred Humboldtianum with light-coloured ejecta from local impact craters and the huge 200-kilometre (124-mile) wide crater Bel'kovich that intrudes upon Mare Humboldtianum's northeastern flank, straddling the lunar near and far sides.

The feature was named Mare Humboldtianum in 1837 by German astronomer and selenographer Johann Heinrich von Mädler in honour of his compatriot, the naturalist and explorer Alexander von Humboldt. Humboldt's explorations of unfamiliar terrestrial continents in the late 18th and early 19th centuries formed a symbolic analogy to Mädler's own lunar surveys, and therefore Mare Humboldtianum represented a physical link between the known and then-unknown hemispheres of the Moon. Viewed from above, Mare Humboldtianum appears as a broad crescent, and it was first pictured from space by the Soviet probe Luna 3 in October 1959.

The Moon's northeastern limb will be visible between 1 and 8 December, which enables Mare Humboldtianum to be seen very well. The best evenings to spot the elusive lunar sea are between 1 and 6 December, with the most favourable viewing on 6 December. Binoculars will easily realise it as a dark patch near the northeastern, or upper-right, edge of the Moon, and a telescopic view will show considerable detail, even though it's illuminated by a relatively high Sun and no shadows will be cast by any of its relief features.

© NASA



NAKED EYE AND BINOCULAR TARGETS

As Christmas looms on the horizon, relax by enjoying these celestial treats

1 Pollux (Beta Geminorum)

Pollux is the second-brightest star in Gemini and the 17th-brightest in the sky, shining at a magnitude of +1.14. It is also one of the few naked-eye stars we know has an extrasolar planet orbiting it – it's bigger than Jupiter and orbits Pollux once every 589 days.

2 Orion Nebula (Messier 42)

This is probably the most famous nebula in the entire sky. It's a vast glowing cloud of gas and dust, a stellar nursery where stars are being born. A 'fuzzy star' to the naked eye, binoculars show it as a small misty-grey smudge on a moonless night.

3 Betelgeuse (Alpha Orionis)

Betelgeuse is an enormous red star, with a diameter over 650 times that of our Sun. With its distinctive orange-red colour and magnitude of +0.42, the supergiant star is immediately visible to the naked eye rising in the east after sunset during the evenings.

4 Messier 41

This star cluster is an amazing 2,350 light years away. Although it's bright enough for the naked eye to see under skies untouched by light pollution, you'll need binoculars to spot this small but pretty star cluster. You can find it shining beneath Sirius because it will be quite low in the sky all night.

5 Sirius (Alpha Canis Majoris)

By far the brightest star in the sky at magnitude -1.46, Sirius is just 8.7 light years away, making it the fifth-closest star to us. To the naked eye, Sirius is a striking blue-white star that shimmers and twinkles dramatically as it shines above the horizon on frosty winter nights.

6 Messier 78

DEEP SKY CHALLENGE

TACKLE THE GREAT TREASURES OF ORION

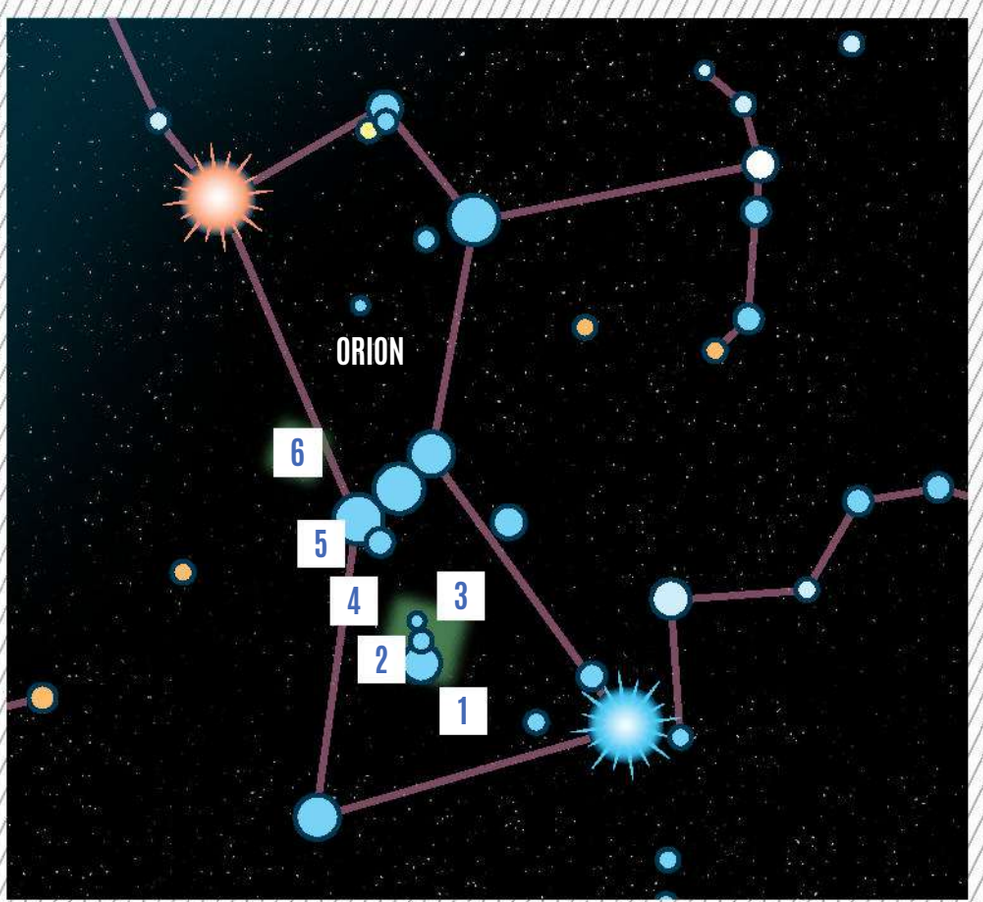
Turn your telescope to the Hunter for a splendid selection of deep-sky targets

The famous constellation of Orion (the Hunter) is littered with deep-sky objects to explore. There are star clusters and nebulae, and that's not including one of the most famous star-forming regions, the Orion Nebula (Messier 42).

Orion is a treasure trove for those interested in seeking out challenges for the eye and telescope alike. The Orion Nebula is easy to spot as one of the brightest nebulae, and is even discernible to the naked eye under even the most mediocre observing conditions. Nearby, another well-known nebula rests that is a lot trickier to spot, and really needs a filter to help make it out: Barnard 33, dubbed the Horsehead Nebula for its equine silhouette, which is created by pillars of gas and dust.

2 De Mairan's Nebula (Messier 43)

3 Running Man Nebula (NGC 1977)



1 The Orion Nebula (Messier 42)

Using your telescope or decent binoculars, look for the four bright stars at its heart – the Trapezium Cluster. Small telescopes at higher magnifications will reveal four of the cluster's brightest stars.

2 De Mairan's Nebula (Messier 43)

This nebula sits on top of the much larger Messier 42 and can be resolved using a medium-powered eyepiece. The object appears separated by a dark dust lane in the foreground and is bursting with a wealth of star formation.

3 Running Man Nebula (NGC 1977)

This beautiful object is a combination of a reflection nebula and HII region. You will need a medium-sized telescope and filters to truly play up the layers of gas and dust.

4 Horsehead Nebula (Barnard 33)

Quite a difficult object to see visually due to its low contrast, the Horsehead Nebula requires a medium to large-aperture telescope equipped with a H-beta filter in order to pick out its structure. Imaging can bring out its pink glow, caused by the hydrogen gas.

5 Flame Nebula (NGC 2024)

NGC 2024 is also known quite fittingly as the Flame Nebula. Alnitak, the brightest star in Orion's Belt, shines ultraviolet light into the Flame Nebula to give it its stunning glow. Filters will help you play up the object's true splendour.

6 Messier 78

There's a star embedded in this nebulosity which reflects its light and allows observers to make out the tenuous gas, even with a small telescope. Two stars are responsible for making the cloud of dust, called HD 38563A and HD 38563B.

© Will Tirion; Ngc1535: ESO/Igor Chekalin; ESA/Hubble & NASA

THE NORTHERN HEMISPHERE

The December constellations offer an impressive array of targets to enjoy

If you're a fan of splitting double stars with your telescope, head over to the constellation of Aries (the Ram), which makes its appearance this month, bounded by the star patterns of Taurus (the Bull), Pisces (the Fishes) and Cetus (the Whale). In particular, binary star systems Lambda Arietis, Epsilon Arietis and Gamma Arietis are splendid targets to resolve for astronomers with medium to large-sized telescopes. Meanwhile, orange giants Hamal (the Head of the Ram) and Botein (Little Belly) can be picked out using nothing more than the naked eye. Orion (the Hunter) is also prominent, featuring red supergiant Betelgeuse, De Mairan's Nebula (Messier 43) and the famous Orion Nebula (Messier 42).

Deneb (Alpha Cygni)

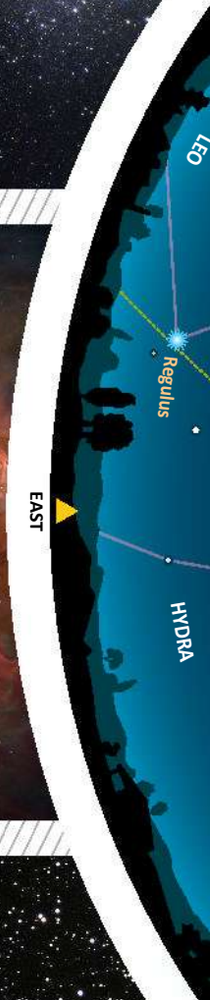
The Orion Nebula (Messier 42)

Messier 37

Using the sky chart

This chart is for use at 22:00 mid-month and is set for 52 degrees latitude.

1. Hold the chart above your head with the bottom of the page in front of you.
2. Face south and notice that north on the chart is behind you.
3. The constellations on the chart should now match what you see in the sky.



Magnitudes

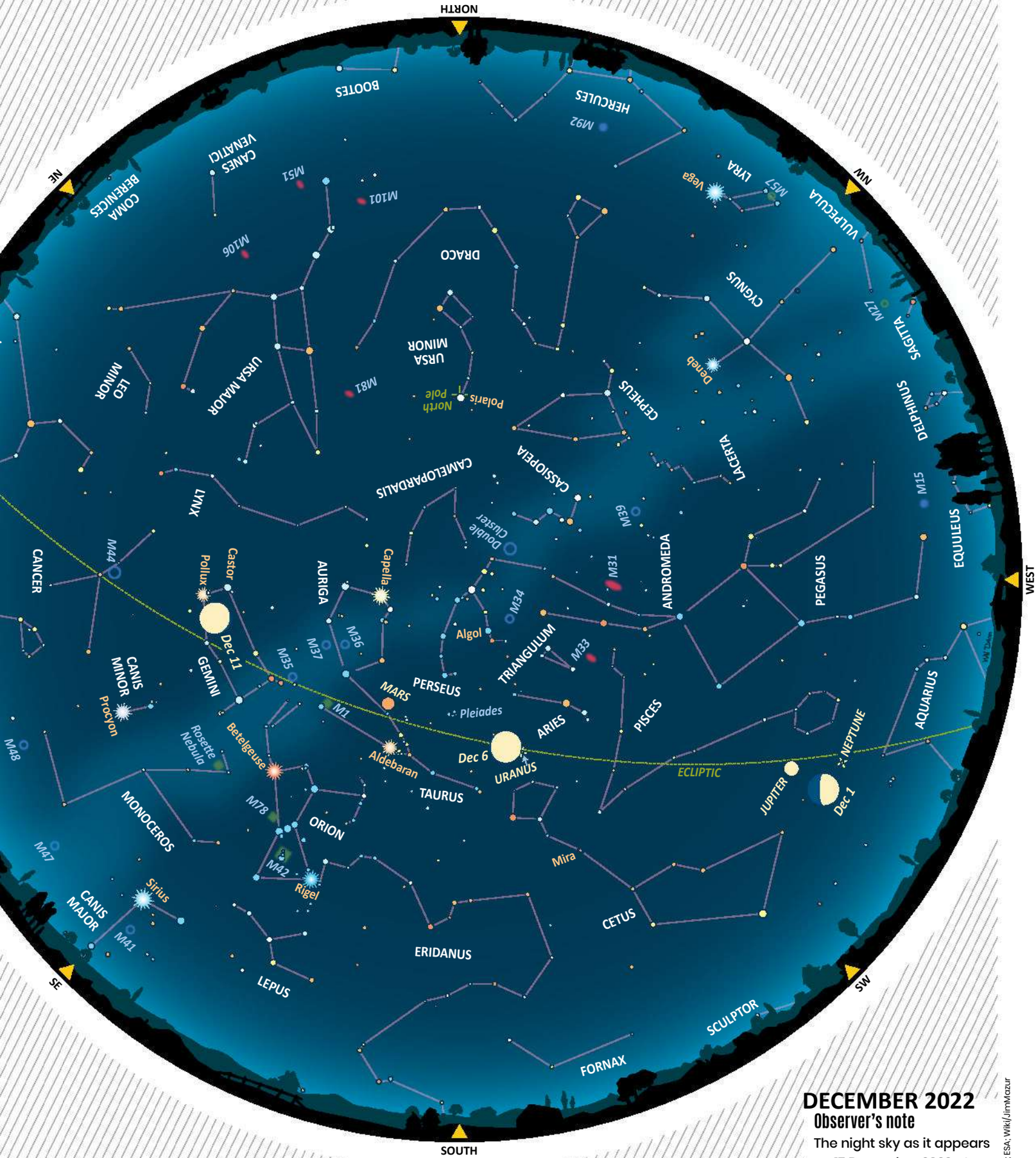
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to +0.5
- +0.5 to +1.0
- +1.0 to +1.5
- +1.5 to +2.0
- +2.0 to +2.5
- +2.5 to +3.0
- +3.0 to +3.5
- +3.5 to +4.0
- +4.0 to +4.5
- Fainter
- Variable star

Spectral types

- O–B
- A
- F
- G
- K
- M

Deep-sky objects

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies



DECEMBER 2022

Observer's note

The night sky as it appears on 17 December 2022 at approximately 22:00 (GMT)

© NASA; ESA; Wiki/JimMazur

ASTROSHOTS OF THE MONTH

ANTOINE AND DALIA GRELIN

Location: Nelson's Landing, Nevada

"Myself and my wife Dalia took our first evening trip into the desert and were completely astonished by how many stars were visible. Las Vegas might be one of most light-polluted cities in America, but it's surrounded by land untouched by light pollution. That night we took a couple of photos with our point-and-shoot camera, which of course were not great, but we could see the Pleiades (Messier 45) in one of them – it was from that point that we immediately fell in love with photographing the night sky.

"We now have enough experience to capture beautiful deep-sky objects using our DSLR and our telescope and enjoy teaching astrophotography to others. We created a YouTube channel, Galactic Hunter, where we make mini-films and tutorials about photographing deep-sky objects in the hope of assisting as many amateur astrophotographers as possible."

Wide-angle view of nebulae in Orion

Soul Nebula (IC 1848)

PAUL SWIFT

Location: Valencia, Spain

Telescope: Vixen VSD 100 f/3.8

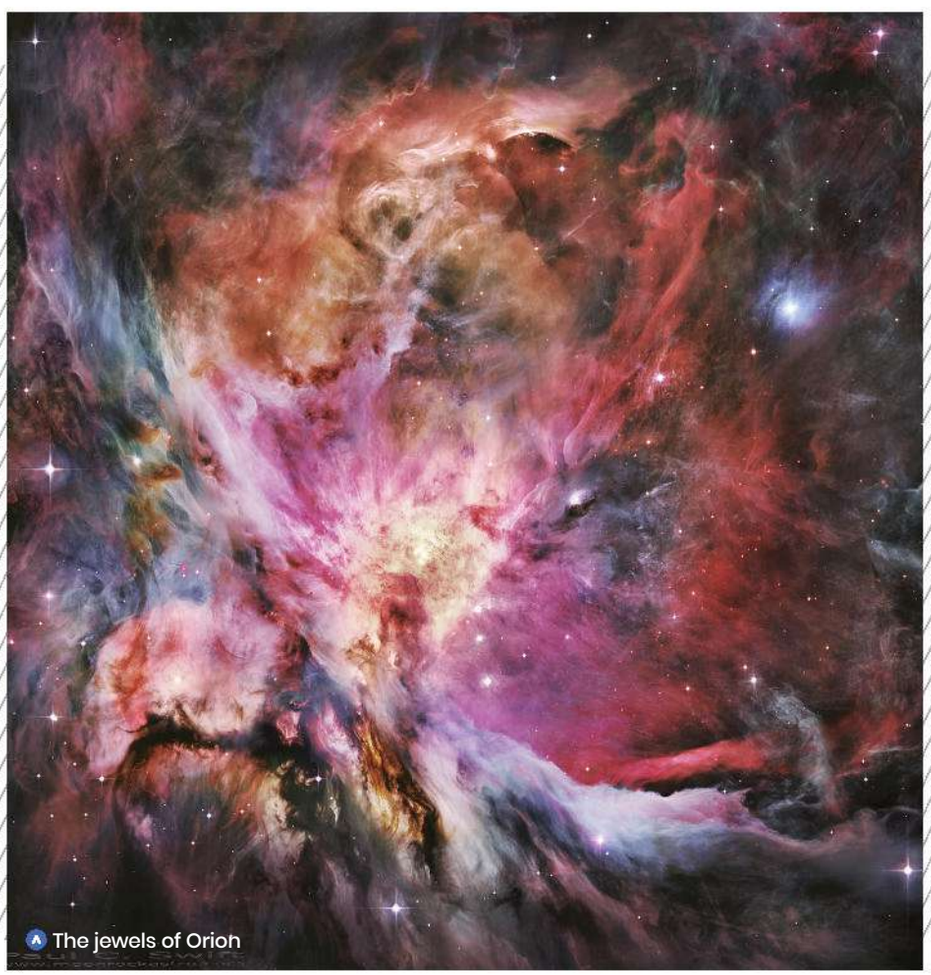
"Having had a background in the arts and working professionally as a cinematographer and lighting cameraman, astrophotography made for a natural change in focus. I had always wanted to turn my camera to the skies. A move away from London to Valencia presented me with the perfect opportunity to do just that. The combination of exploring deep space and the creative and technical art form that is astrophotography offered a powerful and alluring vocation. Any clear night I can be found setting up under darkening skies for a night of photography, and who knows, perhaps a new discovery."

WARREN KELLER

Location: West Virginia

Telescope: 16-inch RCOS Ritchey-Chrétien owned by the University of North Carolina

"I began exploring the night sky at 15 years old with an eight-inch Newtonian during the 1960s. It wasn't until 1998 that I got my first taste of astroimaging with film, and in 2003 I switched to a CCD for capturing the treasures of the night sky. Artistic by nature, it's less about cosmology and more about the thrill of the hunt for the myriad of beautiful shapes and colours throughout the universe. My astrophotography tutorial business has given thousands a quick start in taking their own great photos."


The jewels of Orion

REVIEW

CELESTRON ASTRO FI 102 TELESCOPE

Its reasonable price, motorised functionality and SkyPortal app make this a good telescope for beginners

Reviewed by Jason Parnell-Brookes

The Celestron Astro Fi 102 is an easy-to-set-up motorised Go-To telescope that would be ideal for budding astronomers on a modest budget who are looking for a telescope from a trusted brand. Thanks to its compact body, it's easy to move from place to place, and because it's a Go-To Wi-Fi-enabled telescope, no prior knowledge of the night sky is needed to start exploring and enjoying it.

The images produced are pleasing, especially considering the price, with some expected image fall-off around the edge of the field of view. Despite this, we'd recommend it as a beginner telescope. Alternatively, this would suit someone interested in astronomy that wants to observe celestial objects without learning to navigate the night sky themselves. Similarly, we'd recommend it for those without the desire to push their astronomy knowledge beyond the basics,

TELESCOPE ADVICE

Cost: £379 / $529.95

From: Celestron

Aperture: 102mm

Focal length: 1,325mm

Eyepiece focal length: 25mm and 10mm

Total kit weight: 2.7 kilograms

Mount type: Computerised alt-azimuth

The Astro Fi 102 would be a good starter telescope for children or beginners

as the opportunity for this with the Astro Fi 102 is limited. However, we do think this telescope is worth scoping out.

Weighing in at just 2.7 kilograms, you can take the Celestron Astro Fi 102 anywhere – a great grab-and-go option without having to empty your car boot to make room for your telescope or plan extra luggage allowance for your trip. You could easily take it with you on a hike and forget you're carrying it. Its compact size also makes storing it much easier than larger telescopes, which can take up considerable space.

Of course, to make it lightweight and relatively affordable – for a motorised Maksutov-Cassegrain, anyway – there have been some compromises on quality, especially regarding the final finish on the telescope. The plastic casing is acceptable, but we don't think it could survive a substantial knock or a soaking from a passing shower as the seals aren't great, unlike some of the hardier, fully sealed telescopes available.

A little manipulation of the single-fork arm base and you can virtually peer into the motor housing, viewing wires and more. While astronomers don't tend to head out in a rain storm to view the stars, the odd passing shower does come from nowhere sometimes, so those wanting to grab this telescope will want to cover it before it starts raining to avoid any damage to their kit.

The adjustable tripod is pretty flimsy, although the accessory tray, which holds the eyepieces and any other miscellaneous accessories needed for an observing session, is quite handy to stabilise the tripod legs. The finderscope is very helpful in aiding the alignment and location of stars. As standard with red dot finder telescopes, its bright-red illumination can be dimmed via the controlling knob on the side to suit whatever observing situation you're in, whether it's just after dusk in a city or a fully dark night sky reserve in the middle of nowhere. It slides onto the tube as easily as the tube does onto the single-fork arm's dovetail mount – with minimal fuss.

The images you see through this telescope aren't going to blow your mind, but you will be treated to good views of the Moon and its craters. You'll also get a closer look at Saturn's famous rings, Mars and the giant Jupiter. You may see Uranus and Neptune, too, in the right conditions.

The edges are a little soft, but we'd only expect edge-to-edge sharpness from much more expensive telescopes.

It's quick and easy to sync with the SkyPortal app, which can be set up on any smart device with the Apple App Store or Google Play. The telescope has integrated Wi-Fi, and despite some previous reviews we had read before testing, it seemed stable and reliable when paired with our Android device. The SkyPortal app features around 100,000 celestial objects to which you can make your motorised Go-To telescope automatically slew. It slews at a reasonable rate and is not as frustratingly slow as some can be. It's pretty quiet too. You can also use a USB game controller to slew and position the telescope if you're a gamer or want that extra-sensitive control over the telescope's movements. Alternatively, you can use Celestron's remote hand controller for an additional cost.

The Celestron Astro Fi 102 comes with an integrated smartphone holder in the form of some simple elastic straps built into the lens cap. It seems a little unnecessary, but it might be a useful tool for people who put their phone down between uses and are prone to forgetting where they have left it. One slight oversight we found is the build quality of the battery pack, which we

The telescope comes with a 25mm and 10mm eyepiece

BEST FOR...

- REASONABLE BUDGET
- PLANETS
- FAMILIES
- MOON
- BRIGHT DEEP-SKY OBJECTS

"Its compact size also makes storing it much easier than larger telescopes, which can take up considerable space"

© Jason Parnell-Brookes

We'd recommend a sturdier tripod, but this one does the job

A red dot finderscope is included with the Astro Fi 102

plugged into a 12V DC port. The power cable can become twisted around the mount when the telescope is slewing, and the copper cables are easily pulled out of the basic crimped connections. More advanced models have overcome this problem by having a robust jack port, external inputs and battery bank built into a stationary section of the mount, which stops cables from being overstretched or twisted. That or a more robust connection, perhaps sealed or supported by heat-shrink plastic, would help avoid this problem. We should also mention that once you've finished using the finderscope, turn it off to preserve power. It's fiddly to change the battery, so it's best to have to do it as little as possible.

The Astro Fi 102 is a good telescope for a child or beginner who wants to look at the Moon and some planets, but it would be a struggle for those that want to take it further with additional accessories to achieve what they need. With telescopes, you usually get what you pay for, which rings true with the Celestron Astro Fi 102. The quality and durability won't win any awards, but with care you shouldn't have any problems using this for plenty of skywatching enjoyment. We're pleased with its compact size, thanks to the Maksutov-Cassegrain design, and minimal weight. To get maximum enjoyment out of it, we'd suggest investing in a sturdier tripod for greater stability.

"The images you see through this telescope aren't going to blow your mind, but you will be treated to good views of the Moon and its craters"

FOR

- ⊕ Very portable thanks to its lightweight design
- ⊕ Reasonably and fairly priced
- ⊕ No prior experience is needed

AGAINST

- ⊖ Optics could be better
- ⊖ The tripod isn't the best quality
- ⊖ Doesn't feel like a premium product to the touch

© Jason Parnell-Brookes

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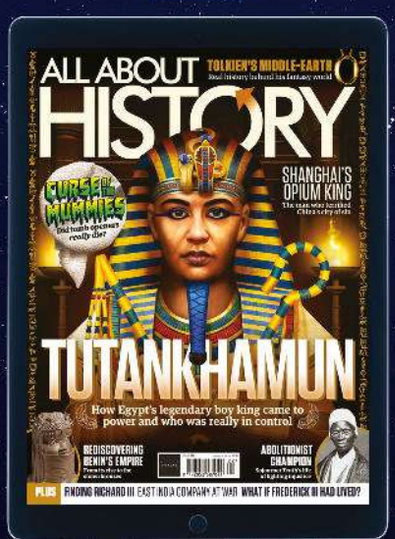
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CHRISTMAS GIFT GUIDE

With the holiday season just around the corner, All About Space selects presents that are sure to delight any space fan

For observers

Night Sky Almanac 2023

Cost: £9.99 / $14.95
From: HarperCollins

1 A lovely stocking filler for anyone interested in stargazing. Follow the progress of constellations throughout the seasons with this stunning companion to the night sky, approved by the astronomers of Royal Observatory Greenwich. This book is packed with month-by-month information about the Moon, stars and planets, as well as details on celestial events to look out for in 2023, from eclipses to meteor showers.

For stocking fillers

How It Works Book of Space

Cost: £9.99 / $11.99
From: magazinesdirect.com

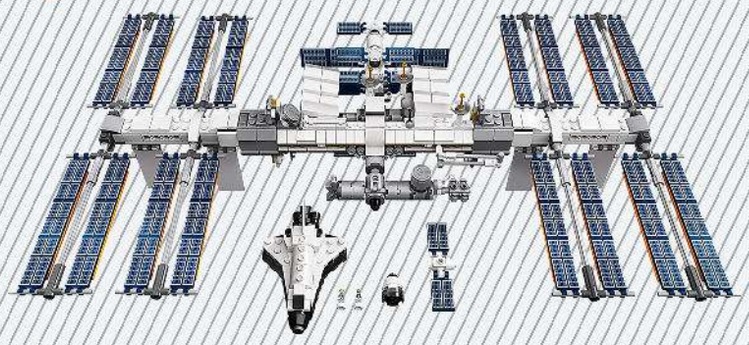
2 As we keep scratching the surface of the vast universe in which we live, our awe and wonder continue to grow. Now, with the technological advancements being made by the world's space agencies, we understand more than ever about the things that are happening beyond our own planet. This new edition of the **How It Works Book of Space** has been updated with more of the latest astronomical advancements, stunning space photography and glimpses at what the future of space exploration holds.

For seasoned astronomers

Celestron Nexstar Evolution 9.25" EdgeHD with StarSense

Cost: £3,749 (approx. $4,417.95)
From: Celestron

3 The NexStar Evolution EdgeHD 9.25 with StarSense is a computerised telescope made for visual observing and certain types of astroimaging. Unique features include StarSense AutoAlign, EdgeHD optics, integrated Wi-Fi and its internal lithium iron phosphate battery. StarSense simplifies alignment and allows more precious time for observations. EdgeHD optics are an aplanatic, flat-field Schmidt design that produce aberration-free images across a wide visual and photographic field of view.



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For your home

Homestar Original

Cost: £104 (approx. $122.50)
From: Sega Toys

4 Imagine enjoying a sky full of stars from the comfort of your own home. This dream can become reality with the Homestar Original from Sega Toys. This high-definition planetarium has an ultrabright three-watt LED and rotating movement that can project the night sky onto your ceiling throughout the year. Two interchangeable discs containing the fixed stars of the Northern Hemisphere will enable you to observe the night sky or a map of the constellations from your home.

For future engineers

LEGO International Space Station

Cost: £59.99 / $69.99
From: LEGO

5 This 864-piece model is a fantastic challenge to build and will leave you with great satisfaction when finished. It includes a 148-page booklet featuring information on the real ISS, and the final model includes two rotating joints with eight adjustable solar panels and other authentic details to discover as you build. There's also a stand, two astronaut Minifigures, a brick-built mini NASA Space Shuttle and three cargo spacecraft to create a spectacular display.

For beginner astronomers

Celestron StarSense Explorer 8" Dobsonian

Cost: £649.99 / $799
From: Celestron

6 Celestron has reinvented the Dobsonian telescope with StarSense Explorer, the first Dobsonian that uses your smartphone to analyse the night sky and calculate its position in real time. The app has a user-friendly interface and detailed tutorials; it's like having your own personal tour guide of the night sky. The large eight-inch aperture will ensure that you won't outgrow the telescope as you continue in your astronomical adventures.

HEROES OF SPACE

GORDON COOPER

Cooper flew a solo mission in space and set flight endurance records

Born on 6 March 1927 in Shawnee, Oklahoma, Cooper left school at the age of 18 and enlisted in the US Marine Corps. Upon his discharge, he moved to Hawaii to live with his parents, attending the island's university before being placed on active duty with the United States Air Force. He then flew fighter jets in West Germany between 1954 and 1955 in the midst of the Cold War ahead of completing his degree in aerospace engineering. By the end of the decade, he had logged more than 7,000 hours of flight time.

But then his career took an unexpected turn. As the Space Race with the Soviet Union was in full swing, Cooper was invited to a secret military meeting in Washington DC, where the discussions were centred on putting a man into Earth orbit and returning him safely, hopefully before the Soviets did the same. Cooper put his name forward, and after a tough application process he gained his place on what was called Project Mercury, along with six others. Together they became known as the Mercury Seven. Their task was to pilot manned spaceflights, which took place between May 1961 and May 1963.

Cooper's flight was the final one. It took place on 15 May 1963 on board the Mercury-Atlas 9 spacecraft, launching from Cape Canaveral, Florida. He orbited Earth 22 times – during which he became the first American to sleep in space – before splashing down in the Pacific Ocean. There had been some potential heart-in-mouth moments on the 21st orbit when system malfunctions forced Cooper to carry out some of the re-entry steps manually, but the 34 hours 19 minutes and 49 seconds he spent on board the spacecraft was more than the previous five Mercury missions combined.

Buoyed by his experience, he remained with NASA, and he ended up flying again in 1965 as the command pilot of Gemini 5 on a mission which took him and Conrad around Earth 120 times, chalking up 5,331,745 kilometres (3,312,993 miles) over eight days. It was a major victory in the ongoing Space Race since it more than overturned a record that had been set by the Soviets two years earlier with Vostok 5 – that mission had lasted 4 days, 23 hours and 7 minutes, completing 82 orbits. Gemini 5 was nevertheless Cooper's last spaceflight.

Though he was the commander of the backup crews for Gemini 12 in 1966 and Apollo 10 in 1969, he became frustrated at not being chosen for a Moon landing mission and he retired from NASA and the Air Force in 1970. Cooper sadly died at the age of 77 from heart failure on 4 October 2004.

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ON SALE 29 DECEMBER

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ALL ABOUT SPACE

Future PLC Quay House, The Ambury, Bath, BA1 1UA

Editorial
Content Director **Gemma Lavender**
gemma.lavender@futurenet.com
Art Editor **Jonathan Wells**
Production Editor **Nikole Robinson**
Senior Art Editor **Duncan Crook**

Contributors
Stuart Atkinson, Tyler Bourke, Keith Cooper, David Crookes, Luke Dones, Donald Figer, Robin Hague, Adrian Hamers, Adam Jermyn, Andrew Jones, Laura Mears, Jonathan O'Callaghan, Tereza Pultarova, Claudia de Rham, Kulvinder Singh Chadha, Doris Elin Urrutia, Miguel Zumalacarregui

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Advertising
Media packs are available on request
UK Commercial Director **Clare Dove**
clare.dove@futurenet.com
Advertising Manager **Matthew Johnson**
matthew.johnston@futurenet.com
07974 408 083
Account Manager **Hayley Brailey-Woolfson**
hayley.brailleywoolfson@futurenet.com
01643 678 054

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Group Marketing Director, Magazines & Memberships **Sharon Todd**
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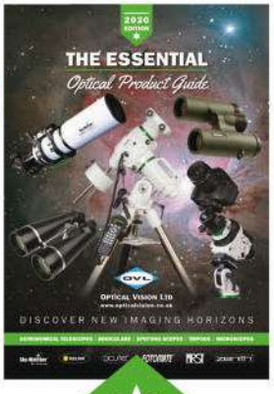

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